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HANDBOOK OF HYDRAULICS

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OF

HYDRAULICS

FOR THE SOLUTION OF
HYDRAULIC PROBLEMS

BY

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PREFACE

In applied Hydraulics rational theory must give place to experimental knowledge. Though every particle of flowing water moves in accordance with definite fixed laws, such laws are intricate and imperfectly understood. In many instances the basic formulas used in hydraulic computations are derived from theoretical considerations, but they must invariably be corrected by experimental coefficients and frequently they become thereby so transformed as to bear but a slight resemblance to the original formulas.

Many thousands of experiments on flowing water have been performed during the last two centuries, the results of which form the basis of our present science of hydraulics. These experiments present many incongruities and as they do not cover the range of conditions required in practice, it is difficult to devise from them accurate working rules and formulas. The hydraulic engineer is therefore confronted with the task of making what appears to be the most reasonable application of the available data to each problem that he encounters.

A great number of empirical formulas have been devised, which provide an indirect method of transferring experimental results to practical problems. In using such formulas, however, the engineer should not lose sight of the fact that results obtained by them will be subject to errors corresponding to the discrepancies in the experiments on which the formulas are based.

The active interest in experimental research during recent years has been productive of such a rapidly increasing number of hydraulic formulas that engineers generally are not in a position to make critical comparisons and select those that possess the greatest merit. The result has been a tendency to cling to the old and accepted formulas. The author believes that unless the newer formulas have apparent advantages over the old, the latter are preferable inasmuch as their peculiarities are known and it is easier to select coefficients for them,

but they should be discarded as soon as more accurate or simpler formulas become available.

In this book the older and commonly accepted formulas are given preference except where a gain in accuracy or simplicity or both will result from the adoption of new formulas or methods. The author departs from standard American practice in advocating the use of the Manning formula in place of the Kutter formula. He has not done this, however, until he has been able to prove that the two formulas give practically identical results by using the same coefficient. New weir formulas are also submitted which are shown to be simpler and to conform to existing experimental data more consistently than other formulas. Exponential formulas are advocated for pipes but a simplified method of using them is given in detail.

This book is intended primarily to assist in the solution of hydraulic problems. In preparing the manuscript the author has continually kept in mind the twofold purpose, of securing an accuracy consistent with the best experiments and of simplifying calculations. This has necessitated an examination of a vast amount of data and has resulted in the preparation of a great many tables. A knowledge of the fundamental principles of hydraulics is presupposed and derivations have been omitted except where they have appeared necessary in explaining new methods. It is believed that the book will be useful to practising engineers and to students.

In the preparation of tables care has been taken to make them correct to the last figure and all computations and formulas have been independently checked. The author will be grateful to those who may call to his attention any errors or omissions.

A work of this kind is, in a large measure, a recompilation of the results of others, and a great many books and publications have necessarily been consulted. Reference to such use has been made at the proper place in the text. In the preparation of this volume the author acknowledges assistance from the following:

Mr. Robert E. Horton reviewed the manuscript and proof and made many valuable criticisms and suggestions relative to the character of material and scope of the book. He gave the author free access to all of the records in his office and many of the data contained herein were obtained from this source. For being able to present the book in its present form

the author is, in a large measure, indebted to Mr. Horton's helpful suggestions, and he takes this opportunity to express his grateful appreciation.

Professor Theodore R. Running rendered valuable assistance in mathematical computations, especially in checking the author's weir formula by the method of least squares and in suggesting the method employed in the construction of the Manning formula diagrams.

Mr. Chester O. Wisler assisted in checking formulas and tables and in reading proof, and gave many valuable suggestions which were made use of in preparing this book.

Mr. Harry R. Leach, Mr. Floyd A. Nagler, and Mr. Russell A. Dodge shared with the author the bulk of the labor of computing and checking tables, reading proof, and other details. It has only been through the hearty coöperation, loyalty, and active interest of these men that the completion of this volume at the present time has been made possible.

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CONTENTS

CHAPTER I

CHAPTER II

CHAPTER III

CHAPTER IV

CHAPTER VIII

CHAPTER IX

CHAPTER X

APPENDIX A

APPENDIX B

TABLES

HANDBOOK OF HYDRAULICS

CHAPTER I

HYDRAULIC UNITS

Basic Units.—In the United States and England the three primary units used as a basis for hydraulic measurements are: the foot, the pound, and the second. If not otherwise stated in this volume, these units will be understood. In countries using the metric system the corresponding units are the meter, the kilogram and the second. Tables 1, 2 and 5, pages 4 and 6, will assist in converting one system of units to the other.

Dimensions, such as diameters of pipes and orifices are frequently expressed in inches, or feet and inches, but these should always be changed to feet and decimals of a foot before substituting in hydraulic formulas. Table 4, page 5, may be used for converting inches to decimals of a foot.

Units of Volume and Flow.—The following units have been used in the United States to express respectively, volumes of water and volumes per time of flowing water:

Volumes:

(*a*) Cubic feet
(*b*) Gallons
(*c*) Acre-feet
(*d*) Cubic feet per second-day
(*e*) Inches per area.

Volumes per time:

(*a*) Cubic feet per second
(*b*) Cubic feet per minute
(*c*) Gallons per minute
(*d*) Gallons per 24 hours
(*e*) Miner's inches
(*f*) Square inches of water
(*g*) Inches per area per time.

The cubic foot is the most convenient unit of volume for expressing small quantities of water, such as capacities of tanks or small reservoirs. Water, in cities, is commonly sold on the basis of the number of cubic feet consumed.

The United States gallon, which contains 231 cubic inches or 0.13368 cubic feet, is the standard of liquid measure. It is commonly used to express volumes in connection with municipal water supply. Reservoir capacities are frequently stated in millions of gallons.

An acre-foot of water is the volume required to cover an area of 1 acre to the depth of 1 foot and is therefore equal to 43,560 cubic feet. This unit has been quite generally adopted in the irrigated sections of the United States and its use is becoming prevalent throughout the country. One cubic foot per second flowing for 24 hours equals 1.9835 acre-feet, or 2 acre-feet within an error of less than 1 per cent. Since hydraulic data are never accurate enough to justify the use of a closer value it is customary to consider that 1 second-foot flowing for 24 hours equals 2 acre-feet. In the author's opinion the acre-foot is the most convenient unit for expressing large volumes of water for the following reasons:

(*a*) It is convenient for irrigation purposes since it includes the standard unit of land area.

(*b*) It is convenient to reduce the capacities of reservoirs to this unit, where areas are expressed in acres.

(*c*) It is convenient for storage calculations since it may readily be transferred to or from units of flow.

(*d*) It enables large volumes to be expressed without the use of extremely large numbers.

The cubic foot per second-day or *second-foot-day* is a volume of water equal to a flow of 1 cubic foot per second for 24 hours or 86,400 cubic feet, or, approximately 2 acre-feet. This unit is sometimes used in storage computations.

Inches per area or simply *inches depth* is a unit generally used in connection with drainage areas. Precipitation and evaporation records are given in inches, the area to which the depth applies being frequently understood. A depth of 1 inch over an area of 1 acre is called an *acre-inch.* An acre-inch is equal to $1/12$ acre-foot or 3630 cubic feet.

A number of units expressing *volume per time* are used in hydraulic work. The most common practice in the United States and Great Britain is to express the volume of flowing water in *cubic feet per second.* The abbreviated term *second-feet* has been adopted by the U. S. Geological Survey and the U. S. Reclamation Service and is used quite generally by American engineers. In England, India and Australia the term *cusecs*

is more commonly used. The author has adopted the term *second-feet* in this volume as it is more in accord with American usage. This unit is gradually supplanting other units, hitherto used in special classes of work, which are defined below.

The unit, *cubic feet per minute* is used by millwrights and turbine manufacturers.

The capacities of pumps are generally expressed in *United States gallons per minute.*

The capacities of water-works plants or the consumption of water by municipalities is usually stated in *gallons* or *millions of gallons per* 24 *hours.*

The miner's inch was formerly used in hydraulic mining and irrigation in Western United States. It is defined as the quantity of water which will flow through an orifice 1 inch square under a stated head which varies from 4 inches to 6½ inches in different localities. The use of this unit has lead to much confusion and its value in terms of cubic feet per second (see Table 5) has been fixed by statute in most of the Western States.

Square inches of water is a unit which was formerly much used by millwrights and waterwheel builders. It commonly means the theoretical discharge through an orifice of a given cross-section, without contraction, under some particular head. Early millwrights in many cases failed to distinguish between the area of the orifice and the area of the jet and much confusion has resulted.

In comparing the run-off from a drainage area with the precipitation, it is often convenient to express the run-off in terms of *inches per month* or *inches per year.* In this connection it may be helpful to remember that 1 *acre-inch per hour equals approximately* 1 *second-foot.*

The use of cubic feet per second may properly displace the units cubic feet per minute, U. S. gallons per minute, U. S. gallons per 24 hours, miner's inches, and square inches of water in practically all instances where these units have hitherto been used. There is no reason why the supply of water to a town should be expressed in gallons per 24 hours, when the water sold to consumers is generally measured and charged for in terms of cubic feet. Likewise, the capacities of pumps and the discharge of turbines may be as readily expressed in cubic feet per second as in terms of the units now commonly used. Table 5, page 6, gives the conversion factors, with their logarithms, for converting one system of units to another.

Table 1.—Conversion of Units of Length

Meters to Feet

Meters	0	1	2	3	4	5	6	7	8	9
		3.28	6.56	9.84	13.12	16.40	19.68	22.97	26.25	29.53
10	32.81	36.09	39.37	42.65	45.93	49.21	52.49	55.77	59.06	62.34
20	65.62	68.90	72.18	75.46	78.74	82.02	85.30	88.58	91.86	95.14
30	98.42	101.71	104.99	108.27	111.55	114.83	118.11	121.39	124.67	127.95
40	131.23	134.51	137.79	141.08	144.36	147.64	150.92	154.20	157.48	160.76
50	164.04	167.32	170.60	173.88	177.16	180.45	183.73	187.01	190.29	193.57
60	196.85	200.13	203.41	206.69	209.97	213.25	216.53	219.82	223.10	226.38
70	229.66	232.94	236.22	239.50	242.78	246.06	249.34	252.62	255.90	259.19
80	262.47	265.75	269.03	272.31	275.59	278.87	282.15	285.43	288.71	291.99
90	295.27	298.56	301.84	305.12	308.40	311.68	314.96	318.24	321.52	324.80

Feet to Meters

Feet	0	1	2	3	4	5	6	7	8	9
		0.305	0.610	0.914	1.219	1.524	1.829	2.134	2.438	2.743
10	3.048	3.353	3.658	3.962	4.267	4.572	4.877	5.182	5.486	5.791
20	6.096	6.401	6.706	7.010	7.315	7.620	7.925	8.230	8.534	8.839
30	9.144	9.449	9.754	10.058	10.363	10.668	10.973	11.278	11.582	11.887
40	12.192	12.497	12.802	13.106	13.411	13.716	14.021	14.326	14.630	14.935
50	15.240	15.545	15.850	16.154	16.459	16.764	17.069	17.374	17.678	17.983
60	18.288	18.593	18.898	19.202	19.507	19.812	20.117	20.422	20.726	21.031
70	21.336	21.641	21.946	22.250	22.555	22.860	23.165	23.470	23.774	24.079
80	24.384	24.689	24.994	25.298	25.603	25.908	26.213	26.518	26.822	27.127
90	27.432	27.737	28.042	28.346	28.651	28.956	29.261	29.566	29.870	30.175

Table 2.—Conversion of Units of Weight

Kilograms to Pounds Avoirdupois

Kilograms	0	1	2	3	4	5	6	7	8	9
		2.20	4.41	6.61	8.82	11.02	13.23	15.43	17.64	19.84
10	22.05	24.25	26.46	28.66	30.86	33.07	35.27	37.48	39.68	41.89
20	44.09	46.30	48.50	50.71	52.91	55.12	57.32	59.52	61.73	63.93
30	66.14	68.34	70.55	72.75	74.96	77.16	79.37	81.57	83.78	85.98
40	88.18	90.39	92.59	94.80	97.00	99.21	101.41	103.62	105.82	108.03
50	110.23	112.44	114.64	116.85	119.05	121.25	123.46	125.66	127.87	130.07
60	132.28	134.48	136.69	138.89	141.10	143.30	145.51	147.71	149.91	152.12
70	154.32	156.53	158.73	160.94	163.14	165.35	167.55	169.76	171.96	174.17
80	176.37	178.57	180.78	182.98	185.19	187.39	189.60	191.80	194.01	196.21
90	198.42	200.62	202.83	205.03	207.23	209.44	211.64	213.85	216.05	218.26

Pounds Avoirdupois to Kilograms

Pounds	0	1	2	3	4	5	6	7	8	9
		0.4536	0.9072	1.361	1.814	2.268	2.722	3.175	3.629	4.082
10	4.536	4.990	5.443	5.897	6.350	6.804	7.257	7.711	8.165	8.618
20	9.072	9.525	9.979	10.433	10.886	11.340	11.793	12.247	12.701	13.154
30	13.608	14.061	14.515	14.969	15.422	15.876	16.329	16.783	17.237	17.690
40	18.144	18.597	19.051	19.504	19.958	20.412	20.865	21.319	21.772	22.226
50	22.680	23.133	23.587	24.040	24.494	24.948	25.401	25.855	26.308	26.762
60	27.216	27.669	28.123	28.576	29.030	29.484	29.937	30.391	30.844	31.298
70	31.752	32.205	32.659	33.112	33.566	34.019	34.473	34.927	35.380	35.834
80	36.287	36.741	37.195	37.648	38.102	38.555	39.009	39.463	39.916	40.370
90	40.823	41.277	41.731	42.184	42.638	43.091	43.545	43.999	44.452	44.906

TABLE 3.—CONVERSION OF UNITS OF POWER

Kilowatts to Horsepower

Kilowatts	0	1	2	3	4	5	6	7	8	9
		1.340	2.681	4.021	5.362	6.702	8.043	9.383	10.724	12.064
10	13.405	14.745	16.086	17.426	18.767	20.107	21.448	22.788	24.129	25.469
20	26.810	28.150	29.491	30.831	32.172	33.512	34.853	36.193	37.534	38.874
30	40.214	41.555	42.895	44.236	45.576	46.917	48.257	49.598	50.938	52.279
40	53.619	54.960	56.300	57.641	58.981	60.322	61.662	63.003	64.343	65.684
50	67.024	68.365	69.705	71.046	72.386	73.727	75.067	76.408	77.748	79.089
60	80.429	81.770	83.110	84.451	85.791	87.132	88.472	89.813	91.153	92.494
70	93.834	95.175	96.515	97.856	99.196	100.54	101.88	103.22	104.56	105.90
80	107.24	108.58	109.92	111.26	112.60	113.94	115.28	116.62	117.96	119.30
90	120.64	121.98	123.32	124.67	126.01	127.35	128.69	130.03	131.37	132.71

Horsepower to Kilowatts

Horsepower	0	1	2	3	4	5	6	7	8	9
		0.746	1.492	2.238	2.984	3.730	4.476	5.222	5.968	6.714
10	7.460	8.206	8.952	9.698	10.444	11.190	11.936	12.682	13.428	14.174
20	14.920	15.666	16.412	17.158	17.904	18.650	19.396	20.142	20.888	21.634
30	22.380	23.126	23.872	24.618	25.364	26.110	26.856	27.602	28.348	29.094
40	29.840	30.586	31.332	32.078	32.824	33.570	34.316	35.062	35.808	36.554
50	37.300	38.046	38.792	39.538	40.284	41.030	41.776	42.522	43.268	44.014
60	44.760	45.506	46.252	46.998	47.744	48.490	49.236	49.982	50.728	51.474
70	52.220	52.966	53.712	54.458	55.204	55.950	56.696	57.442	58.188	58.934
80	59.680	60.426	61.172	61.918	62.664	63.410	64.156	64.902	65.648	66.394
90	67.140	67.886	68.632	69.378	70.124	70.870	71.616	72.362	73.108	73.854

TABLE 4.—INCHES AND FRACTIONS EXPRESSED IN DECIMALS OF A FOOT

Inches	Fractions of inches							
	0	1/8	1/4	3/8	1/2	5/8	3/4	7/8
0	.0000	.0104	.0208	.0313	.0417	.0521	.0625	.0729
1	.0833	.0937	.1042	.1146	.1250	.1354	.1458	.1562
2	.1667	.1771	.1875	.1979	.2083	.2188	.2292	.2396
3	.2500	.2604	.2708	.2813	.2917	.3021	.3125	.3229
4	.3333	.3437	.3542	.3646	.3750	.3854	.3958	.4062
5	.4167	.4271	.4375	.4479	.4583	.4688	.4792	.4896
6	.5000	.5104	.5208	.5313	.5417	.5521	.5625	.5729
7	.5833	.5937	.6042	.6146	.6250	.6354	.6458	.6562
8	.6667	.6771	.6875	.6979	.7083	.7188	.7292	.7396
9	.7500	.7604	.7708	.7813	.7917	.8021	.8125	.8229
10	.8333	.8437	.8542	.8646	.8750	.8854	.8958	.9062
11	.9167	.9271	.9375	.9479	.9583	.9688	.9792	.9896
12	1.0000	......	......	......	......	......	......	......

TABLE 5

Factors for conversion of units. To reduce A to B, multiply A by F. To reduce B to A, multiply B by G

Unit A	Factor F	Logarithm of F characteristics all positive	Logarithm of G characteristics all negative	Factor G	Unit B
LENGTH:					
Miles	63,360.*	4.80182	5.19818	.000015783	Inches
Miles	5,280.*	3.72263	4.27737	.00018939	Feet
Miles	1,609.35	3.20665	4.79335	.00062137	Meters
Miles	1.60935	0.20665	1.79335	.62137	Kilometers
Kilometers	3,280.83	3.51598	4.48402	.00030480	Feet
Meters	3.2808	0.51598	1.48402	.30480	Feet
Yards	36.*	1.55630	2.44370	.027778	Inches
Feet	12.*	1.07918	2.92082	.083333	Inches
Meters	39.370	1.59517	2.40483	.025400	Inches
Inches	2.5400	0.40483	1.59517	.39370	Centimeters
SURFACE:					
Square miles	27,878,400.*	7.44527	8.55473	.000000035870	Square feet
Square miles	640.*	2.80618	3.19382	.0015625*	Acres
Square miles	259.000	2.41330	3.58670	.0038610	Hectares
Acres	43,560.*	4.63909	5.36091	.000022957	Square feet
Acres	4,046.9	3.60712	4.39288	.00024710	Square meters
Hectares	2.47104	0.39288	1.60712	.40469	Acres
Hectares	10,000.*	4.00000	4.00000	.0001*	Square meters
Square feet	144.*	2.15836	3.84164	.0069444	Square inches
Square inches	6.4516	0.80967	1.19033	.15500	Square centimeters
Square meters	10.764	1.03197	2.96803	.092902	Square feet
VOLUME:					
Cubic feet	1,728.*	3.23754	4.76246	.00057870	Cubic inches
Cubic inches	16.387	1.21450	2.78550	.061024	Cubic centimeters
Cubic meters	35.3145	1.54795	2.45205	.028317	Cubic feet
Cubic meters	1.3079	0.11659	1.88341	.76456	Cubic yards
Cubic feet	7.4805	0.87393	1.12607	.13368	U. S. gallons

* Exact values.

TABLE 5 (*Continued*)

Factors for conversion of units. To reduce A to B, multiply A by F. To reduce B to A, multiply B by G

Unit A	Factor F	Logarithm of F characteristics all positive	Logarithm of G characteristics all negative	Factor G	Unit B
VOLUME (*continued*):					
Cubic feet	6.2321	0.79463	1.20537	.16046	Imperial gallons
Cubic feet	28.317	1.45205	2.54795	.035314	Liters
U. S. gallons	231. *	2.36361	3.63639	.0043290	Cubic inches
Imperial gallons	277.274	2.44291	3.55709	.0036065	Cubic inches
Liters	61.0234	1.78550	2.21450	.016387	Cubic inches
U. S. gallons	3.7854	0.57812	1.42188	.26417	Liters
Imperial gallons	1.2003	0.07930	1.92070	.83311	U. S. gallons
Imperial gallons	4.5437	0.65741	1.34259	.22009	Liters
U. S. bushels	1.2445	0.09498	1.90502	.80356	Cubic feet
Fluid ounces	1.8047	0.25640	1.74360	.55411	Cubic inches
Acre-feet	43,560. *	4.63909	5.36091	.000022957	Cubic feet
Acre-feet	1,613.3	3.20772	4.79228	.00061983	Cubic yards
Acre-feet	1,233.5	3.09114	4.90886	.00081071	Cubic meters
Acre-inches	3,630. *	3.55991	4.44009	.00027548	Cubic feet
Millions U. S. gallons	133,681.	5.12607	6.87393	.0000074805	Cubic feet
Millions U. S. gallons	3.0689	6.48698	1.51302	.32585	Acre-feet
Feet depth on 1 square mile	27,878,400. *	7.44527	8.55473	.000000035870	Cubic feet
Feet depth on 1 square mile	640. *	2.80618	3.19382	.0015625*	Acre-feet
Inches depth on 1 square mile	2,323,200. *	6.36609	7.63391	.00000043044	Cubic feet
Inches depth on 1 square mile	53.333	1.72700	2.27300	.01875*	Acre-feet
FLOWING WATER:					
Second-feet	60. *	1.77815	2.22185	.016667	Cubic feet per minute
Second-feet	86,400. *	4.93651	5.06349	.000011574	Cubic feet per 24 hours
Second-feet	448.83	2.65208	3.34792	.0022280	U. S. gallons per minute
Second-feet	646,317.	5.81045	6.18955	.0000015472	U. S. gallons per 24 hours
Second-feet	1.9835†	0.29743	1.70257	.50417	Acre-feet per 24 hours

* Exact values. † Usually taken as 2.

TABLE 5 (*Continued*)

Factors for conversion of units. To reduce A to B, multiply A by F. To reduce B to A, multiply B by G

Unit A	Factor F	Logarithm of F characteristics all positive	Logarithm of G characteristics all negative	Factor G	Unit B
FLOWING WATER (*continued*):					
Second-feet	723.98	2.85972	3.14028	.0013813	Acre-feet per 365 days
Second-feet	50.*	1.69897	2.30103	.02*	Miner's inches, Idaho
Second-feet	50.*	1.69897	2.30103	.02*	Miner's inches, Kansas
Second-feet	50.*	1.69897	2.30103	.02*	Miner's inches, Nebraska
Second-feet	50.*	1.69897	2.30103	.02*	Miner's inches, New Mexico
Second-feet	50.*	1.69897	2.30103	.02*	Miner's inches, N. Dakota
Second-feet	50.*	1.69897	2.30103	.02*	Miner's inches, S. Dakota
Second-feet	40.*	1.60206	2.39794	.025*	Miner's inches, Arizona
Second-feet	40.*	1.60206	2.39794	.025*	Miner's inches, California
Second-feet	40.*	1.60206	2.39794	.025*	Miner's inches, Montana
Second-feet	40.*	1.60206	2.39794	.025*	Miner's inches, Oregon
Second-feet	38.4*	1.58433	2.41567	.026042	Miner's inches, Colorado
Millions U. S. gallons per day	1.5472	0.18955	1.81045	.64632	Second-feet
Inches depth per hour	645.33	2.80978	3.19022	.0015496	Second-feet per square mile
Inches depth per day	26.889	1.42957	2.57043	.037190	Second-feet per square mile
Second-feet per square mile	1.0413	0.01758	1.98242	.96032	Inches depth per 28 days
Second-feet per square mile	1.0785	0.03283	1.96717	.92720	Inches depth per 29 days
Second-feet per square mile	1.1157	0.04755	1.95245	.89630	Inches depth per 30 days
Second-feet per square mile	1.1529	0.06179	1.93821	.86738	Inches depth per 31 days
Second-feet per square mile	13.574	1.13272	2.86728	.073668	Inches depth per 365 days
Second-feet per square mile	13.612	1.13391	1.86609	.073467	Inches depth per 366 days
Acre-inches per hour	1.0083†	0.00360	1.99640	.99173†	Second-feet
Cubic-feet per minute	7.4805	0.87393	1.12607	.13368	U. S. gallons per minute
Cubic-feet per minute	10,772.	4.03229	5.96771	.000092834	U. S. gallons per 24 hours
U. S. gallons per minute	1,440.*	3.15836	4.84164	.00069444	U. S. gallons per 24 hours

* Exact values † Usually taken as unity:

TABLE 5 (*Concluded*)

Factors for conversion of units. To reduce A to B, multiply A by F. To reduce B to A, multiply B by G.

Unit A	Factor F	Logarithm of F characteristics all positive	ogarithm of G characteristics all negative	Factor G	Unit B
VELOCITIES AND GRADES:					
Miles per hour	1.4667	0.16633	1.83367	.68182	Feet per second
Meters per second	3.2808	0.51598	1.48402	.30480	Feet per second
Meters per second	2.2369	0.34965	1.65035	.44704	Miles per hour
Fall in feet per mile	5,280. *	3.72263	4.27737	.00018939	Slope per foot
Slope in seconds of arc	206,265.	5.31443	6.68557	.0000048481	Slope per foot
PRESSURES (0°C. = 32°F.):					
Atmospheres (mean)	14.697	1.16723	2.83277	.068041	Pounds per square inch
Atmospheres (mean)	29.921	1.47598	2.52402	.033421	Inches of mercury
Atmospheres (mean)	760.	2.88081	3.11919	.0013158	Millimeters of mercury
Atmospheres (mean)	33.907	1.53030	2.46970	.029492	Feet of water
Atmospheres (mean)	1.0333	0.01422	1.98578	.96778	Kilograms per square centimeter
Inches of mercury	1.135	0.05500	1.94500	.88106	Feet of water
Pounds per square inch	2.0359	0.30875	1.69125	.49119	Inches of mercury
Pounds per square inch	51.711	1.71359	2.28641	.019338	Millimeters of mercury
Feet of water	62.416	1.79530	2.20470	.016022	Pounds per square foot
Pounds per square inch	2.3071	0.36307	1.63693	.43344	Feet of water
WEIGHT:					
Pounds	7,000. *	3.84510	4.15490	.00014286	Grains
Grams	15.432	1.18843	2.81157	.064799	Grains
Kilograms	2.2046	0.34333	1.65667	.45359	Pounds
Long tons (2240 pounds)	1.12*	0.04922	1.95078	.89286	Short tons
Long tons	1.0160	0.00691	1.99309	.98421	Metric tons (1000 kilograms)
POWER:					
Horsepower	550. *	2.74036	3.25964	.0018182	Foot-pounds per second
Kilowatts	1.3405	0.12726	1.87274	.746	Horsepower
Kilowatts	8,760*	3.94250	6.05750	.00011416	Kilowatt-hours per year
Horsepower	8,760*	3.94250	6.05750	.00011416	Horsepower-hours per year
Horsepower	11,743	4.06977	5.93023	.000085159	Kilowatt-hours per year

* Exact values.

TABLE 5 (*Continued*)

Factors for conversion of units. To reduce *A* to *B*, multiply *A* by *F*. To reduce *B* to *A*, multiply *B* by *G*

Unit *A*	Factor *F*	Logarithm of *F* characteristics all positive	Logarithm of *G* characteristics all negative	Factor *G*	Unit *B*
FLOWING WATER (*continued*):					
Second-feet	723.98	2.85972	3.14028	.0013813	Acre-feet per 365 days
Second-feet	50.*	1.69897	2.30103	.02*	Miner's inches, Idaho
Second-feet	50.*	1.69897	2.30103	.02*	Miner's inches, Kansas
Second-feet	50.*	1.69897	2.30103	.02*	Miner's inches, Nebraska
Second-feet	50.*	1.69897	2.30103	.02*	Miner's inches, New Mexico
Second-feet	50.*	1.69897	2.30103	.02*	Miner's inches, N. Dakota
Second-feet	50.*	1.69897	2.30103	.02*	Miner's inches, S. Dakota
Second-feet	40.*	1.60206	2.39794	.025*	Miner's inches, Arizona
Second-feet	40.*	1.60206	2.39794	.025*	Miner's inches, California
Second-feet	40.*	1.60206	2.39794	.025*	Miner's inches, Montana
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Second-feet	38.4*	1.58433	2.41567	.026042	Miner's inches, Colorado
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TABLE 5 (*Concluded*)

Factors for conversion of units. To reduce *A* to *B*, multiply *A* by *F*. To reduce *B* to *A*, multiply *B* by *G*.

Unit *A*	Factor *F*	Logarithm of *F* characteristics all positive	ogarithm of *G* characteristics all negative	Factor *G*	Unit *B*
VELOCITIES AND GRADES:					
Miles per hour	1.4667	0.16633	1.83367	.68182	Feet per second
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Atmospheres (mean)	1.0333	0.01422	1.98578	.96778	Kilograms per square centimeter
Inches of mercury	1.135	0.05500	1.94500	.88106	Feet of water
Pounds per square inch	2.0359	0.30875	1.69125	.49119	Inches of mercury
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Feet of water	62.416	1.79530	2.20470	.016022	Pounds per square foot
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Grams	15.432	1.18843	2.81157	.064799	Grains
Kilograms	2.2046	0.34333	1.65667	.45359	Pounds
Long tons (2240 pounds)	1.12*	0.04922	1.95078	.89286	Short tons
Long tons	1.0160	0.00691	1.99309	.98421	Metric tons (1000 kilograms)
POWER:					
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Horsepower	11,743	4.06977	5.93023	.000085159	Kilowatt-hours per year

* Exact values.

Table 6.—Average Weight, in Pounds per Cubic Foot, of Various Materials Used in Hydraulic Construction

Substance	Weight	Substance	Weight
Clay, Earth and Mud:		**Masonry and its Materials**—(*continued*):	
Clay	122–162	Sand, pure quartz, dry, loose	87–106
Earth, dry and loose	72–80	Sand, pure quartz, dry, slightly shaken	92–110
Earth, dry and shaken	82–92	Sand, pure quartz, dry, rammed	100–120
Earth, dry and moderately rammed	90–100	Sand, natural, dry, loose	80–110
Earth, slightly moist, loose	70–76	Sand, natural, dry, shaken	85–125
Earth, more moist, loose	66–68	Sand, wet, voids full of water	118–128
Earth, more moist, shaken	75–90	Stone	135–195
Earth, more moist, moderately rammed	90–100	Stone, quarried, loosely piled	80–110
Earth, as soft flowing mud	104–112	Stone, broken, loose	77–112
Earth, as soft mud well pressed into a box	110–120	Stone, broken, rammed	79–121
Mud, dry, close	80–110	**Metal and Alloys:**	
Mud, wet, moderately pressed	110–130	Brass (copper and zinc)	487–524
Mud, wet, fluid	104–120	Bronze (copper and tin)	524–537
Masonry and its Materials:		Copper, cast	537–548
Brick, best pressed	150	Copper, rolled	548–562
Brick, common hard	125	Iron and steel, cast	438–483
Brick, soft, inferior	100	Average	450
Brickwork, pressed brick, fine joints	140	Iron and steel, wrought	475–494
Brickwork, medium quality	125	Average	480
Brickwork, coarse, inferior soft bricks	100	Spelter or zinc	425–450
Cement, pulverized, loose	72–105	Tin, cast	450–470
Cement, pressed	115	Steel	490
Cement, set	168–187	Tin	459
Concrete, 1 : 3 : 6	140	Zinc	438
Gravel, loose	82–125	Mercury (32°F.)	849
Gravel, rammed	90–145	**Woods (dry)***	
Masonry of granite or stone of like weight:		White oak	46.4
Well-dressed	165	White pine	25.6
Well-scabbled rubble, 20 per cent. mortar	154	Southern long-leaf pine	38.1
Roughly scabbled rubble, 25 to 35 per cent. mortar	150	Douglas fir	32.1
Well-scabbled dry rubble	138	Short-leaf yellow pine	38.4
Roughly scabbled dry rubble	125	Norway pine	30.2
Masonry of sandstone or stone of like weight weighs about seven-eighths of the above.		Spruce and eastern fir	25.0
Mortar, hardened	90–115	Hemlock	26–32
		Cypress	29.8
		Cedar	23.1
		Chestnut	41.0
		California redwood	26.2
		California spruce	25.0

* The weights of green or unseasoned timbers are 20 to 40 per cent. greater.

CHAPTER II

HYDROSTATICS

Weight of Water

The maximum density of water occurs at a temperature of 39.3°F. From this point the density decreases with either an increase or decrease in temperature. In the following pages the weight of water is assumed to be 62.4 pounds per cubic foot, which figure is close enough for ordinary engineering computations. Table 7 gives relative densities and weights in pounds per cubic foot of distilled water for different temperatures in degrees Fahrenheit between the freezing and boiling points.

TABLE 7

Temperature	Relative density	Weight	Temperature	Relative density	Weight	Temperature	Relative density	Weight
32	0.99987	62.416	60	0.99907	62.366	140	0.98338	61.386
35	0.99996	62.421	70	0.99802	62.300	150	0.98043	61.203
39.3	1.00000	62.424	80	0.99669	62.217	160	0.97729	61.006
40	0.99999	62.423	90	0.99510	62.118	170	0.97397	60.799
43	0.99997	62.422	100	0.99318	61.998	180	0.97056	60.586
45	0.99992	62.419	110	0.99105	61.865	190	0.96701	60.365
50	0.99975	62.408	120	0.98870	61.719	200	0.96333	60.135
55	0.99946	62.390	130	0.98608	61.555	212	0.95865	59.843

Atmospheric Pressure

Atmospheric pressure on the earth's surface varies with meteorological conditions, and decreases as the altitude increases. At sea level the mean atmospheric pressure averages about 2116 pounds per square foot or 14.7 pounds per square inch, the latter being commonly designated as one atmosphere. This is equivalent to the weight of a column of water 33.92 feet high or a column of mercury 29.92 inches or 760 millimeters high. If, therefore, all of the air is exhausted from a pipe the

lower end of which is immersed in water, at sea level, the water will rise in the pipe to a height of nearly 34 feet.

This principal is made use of in designing siphons, suction pipes for pumps and draft tubes for turbines. In practice a perfect vacuum is difficult to obtain and the height to which a water column may, with safety, be depended upon to rise is about 75 per cent. of the theoretical amount.

Table 8 gives mean atmospheric pressures in pounds per square inch, with corresponding heights of water columns in feet and heights of mercury columns in inches, for different elevations above sea level in feet.

TABLE 8

Elevation	Atmospheric pressure	Height of water column	Height of mercury column	Elevation	Atmospheric pressure	Height of water column	Height of mercury column	Elevation	Atmospheric pressure	Height of water column	Height of mercury column
0	14.70	33.9	29.9	3,000	13.16	30.4	26.8	6,000	11.80	27.2	24.0
250	14.57	33.6	29.6	3,250	13.04	30.1	26.6	6,250	11.70	27.0	23.8
500	14.44	33.3	29.3	3,500	12.92	29.8	26.3	6;500	11.60	26.7	23.6
750	14.31	33.0	29.1	3,750	12.81	29.6	26.0	6,750	11.50	26.5	23.4
1,000	14.18	32.7	28.8	4,000	12.69	29.3	25.8	7,000	11.40	26.3	23.2
1,250	14.05	32.4	28.6	4,250	12.58	29.0	25.6	7,250	11.31	26.1	23.0
1,500	13.92	32.1	28.3	4,500	12.46	28.8	25.4	7,500	11.21	25.9	22.8
1,750	13.79	31.8	28.1	4,750	12.35	28.5	25.1	7,750	11.12	25.7	22.6
2,000	13.66	31.5	27.8	5,000	12.23	28.2	24.9	8,000	11.03	25.5	22.5
2,250	13.53	31.2	27.5	5,250	12.12	28.0	24.7	8,250	10.94	25.3	22.3
2,500	13.41	30.9	27.3	5,500	12.01	27.7	24.5	8,500	10.85	25.1	22.1
2,750	13.28	30.6	27.0	5,750	11.91	27.5	24.3	8,750	10.76	24.9	21.9

Hydrostatic Pressure

The pressure of a fluid at any point, according to *Pascal's law,* is normal to the surface on which it acts and of equal intensity in all directions. Water, being a perfect fluid, conforms rigidly to this law.

The intensity of pressure on any submerged surface is directly proportional to the weight of the fluid and the depth of submergence. A similar pressure is exerted against the sides, and bottom of a vessel or reservoir containing water. The pressure at any point in a body of water with a free surface is equal to the sum of the pressure of the water above it and the atmospheric

pressure. In practice the atmospheric pressure may frequently be neglected as it may act equally on both sides of the surface being considered. This is not necessarily the case, however, and the effect of atmospheric pressure should always be given careful consideration.

Pressure on Plane Surfaces.—Let Figs. 1, 2 and 3, represent submerged, horizontal, vertical and inclined planes respectively. LM, in each figure, represents the horizontal projection of a plane surface of any shape on a vertical plane at right angles

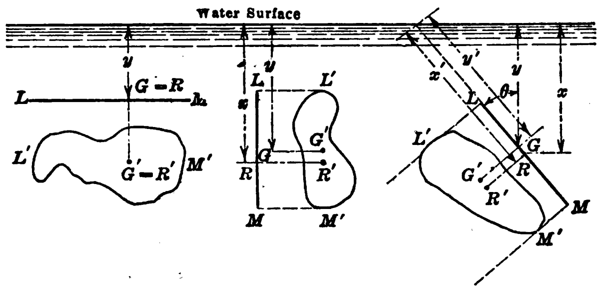


FIG. 1. FIG. 2. FIG. 3.

to the given plane, $L'M'$ being the true size of the given surface. G is the center of gravity and R the point of application of the resultant pressure. y and x are the vertical distances from G and R respectively to the water surface, y' and x' being corresponding distances along the inclined plane, measured at right angles to the intersection of this plane with the water surface. The inclined plane makes an angle θ with the vertical. Let A represent the area of the surface, k the radius of gyration about its horizontal axis through the center of gravity, P the total pressure and w the weight of a cubic unit of water. Then, for each plane

$$P = wAy \tag{1}$$

and for the inclined plane

$$P = wAy' \cos\theta. \tag{2}$$

For a horizontal plane the point of application of the resultant pressure passes through G, the center of gravity of the surface. For a vertical plane

$$x = y + \frac{k^2}{y} \tag{3}$$

and for an inclined plane

$$x' = y' + \frac{k^2}{y'} \tag{4}$$

or

$$x = y + \frac{k^2 \cos^2 \theta}{y} \tag{5}$$

Fig. 4 shows the more common shapes encountered in hydraulic problems, with the vertical distance x from the base to the center of gravity, G, and the squares of the radii of gyration, k^2, about the horizontal axes, through the centers of gravity.

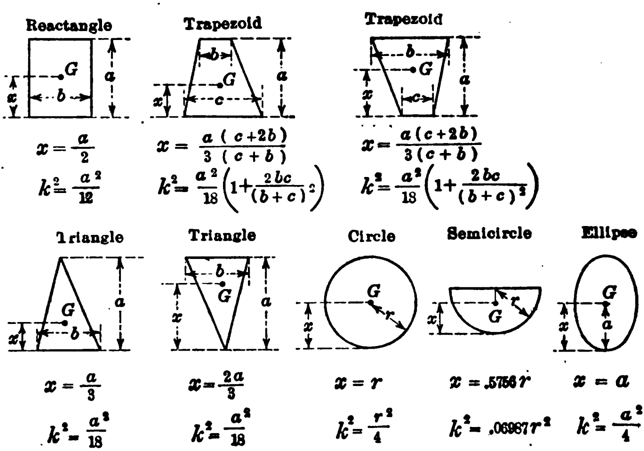


Fig. 4.

Hydrostatic Pressures against Dams

In designing dams all hydrostatic pressures should be carefully analyzed. This includes:

(*a*) Static pressure on upstream and downstream faces of dam.

(*b*) Upward pressure against base of dam.

(*c*) For overflow dams, pressure resulting from the formation of a vacuum beneath the overfalling sheet.

Pressure against Faces of Dams.—Let Figs. 5 and 6 represent cross-sections of dams, D being the vertical height and H the depth of water passing over the dams, both in feet.

The pressure against the face of the dam at a depth y is $62.4y$ pounds per square foot or $0.4333y$ pounds per square inch. Table 9, page 21, gives pressures in pounds per square foot, and Table 10, page 22, pressures in pounds per square inch for different heads. Table 11, page 27, gives heads in feet corresponding to different pressures in pounds per square inch.

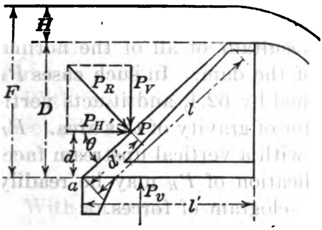


FIG. 5.

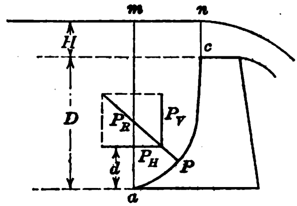


FIG. 6.

The total horizontal pressure is the same, for a given height of dam and depth of water, regardless of the curvature or inclination of the face of the dam. Let P_R be the total or resultant pressure against the face of the dam, and P_V and P_H, respectively, the vertical and horizontal components of this pressure. Then for each case indicated in Figs. 5 and 6,

$$P_H = 31.2\,(2DH + D^2) \tag{6}$$

and calling d the distance above the base of the dam at which P_H acts

$$d = \frac{D}{3}\left(1 + \frac{H}{D + 2H}\right) \tag{7}$$

Tables 12 and 13, pages 29 and 30, give values of P_H and d for heights of dam from 1 to 50 feet and depths of overflow from 0 to 9 feet. These tables may also be used for obtaining P_H and d for other submerged surfaces.

If the water surface is at the same elevation as the top of the dam, $H = 0$ and

$$P_H = 31.2D^2 \text{ and } d = \tfrac{1}{3}D$$

For dams with vertical faces the pressure has no vertical component and

$$P_R = P_H$$

For dams with inclined plane faces, if l is the length from crest to base of dam,

$$P_R = 31.2l(D + 2H) \tag{8}$$

and calling d' the distance above the base of the dam, measured along its face, at which P_R acts

$$d' = \frac{d}{\sin \theta} = \frac{l}{3}\left(1 + \frac{H}{D + 2H}\right) \tag{9}$$

and when $H = 0$

$$P_R = 31.2lD \text{ and } d' = \frac{l}{3}$$

For dams with curved or irregularly sloping upstream faces, illustrated in Fig. 6, P_R is the resultant of all of the normal components acting on the face of the dam. In such cases P_V is equal to the area *amnc* multiplied by 62.4, and it acts vertically downward through the center of gravity of this area. P_H and d are the same as for a dam with a vertical upstream face. The intensity and point of application of P_R may be readily obtained by completing the parallelogram of forces.

Upward Pressure under Dams.—When a solid masonry dam is built on a rock foundation, there is a tendency for water to pass from the pond above the dam, through seams in the rock to the base of the dam. There results an upward hydrostatic pressure and inside of the point where the resultant of the other forces acting on the dam cuts its base, it will have an overturning effect. There is no way to determine to just what extent such a pressure exists but it is evidently greater for the more seamy rocks. It is therefore advisable, in preparing the foundation for such a dam, to remove all loose material and get down to the best rock practicable. A common practice is to construct a cut-off wall of concrete or masonry, extending several feet into firm rock, near the heel of the dam.

Fig. 5 represents a common type of reinforced-concrete dam. It consists of a floor, deck, and buttresses, and usually a cut-off wall at the heel. Such a dam may or may not be subjected to overflow. When it is required to withstand overflow, provision must be made to prevent erosion at the toe. When this type of dam is built on firm rock, the floor may be omitted. With the floor it is well adapted to almost any kind of an earth foundation. The problems of seepage and upward pressure on the base of a dam of this kind are important.

Experiments were performed by Colman[1] to determine conditions affecting upward pressure under dams with permeable foundations. In a measure water passing through earth follows

[1] J. B. T. Colman: The Action of Water under Dams. *Trans.* Amer. Soc. Civ. Eng., vol. 80, pp. 421–483.

the laws of the flow of water through pipes. If water passes under a dam there is a greater static pressure near the heel of the dam than near its toe as there is a loss of head due to friction between these two points.

Referring to Fig. 5, if F represents the depth of water back of the dam in feet, l' the breadth of the base of the dam in feet, and P_u the total upward pressure in pounds per foot of length of dam, the following formulas, as shown from Colman's experiments, appear safe for determining upward pressure under dams on earth foundations:

With no cut-off at the heel of the dam or with ordinary sheet piling

$$P_u = \frac{62.4}{2} Fl' = 31.2Fl' \tag{10}$$

With an impervious cut-off at the heel of the dam

$$P_u = \frac{62.4}{3} Fl' = 20.8Fl' \tag{11}$$

The point of application of the resultant, P_u, in each case is $\frac{1}{3}l'$ from the heel of the dam.

With an impervious cut-off at both the heel and toe of the dam the upward pressure is slightly greater than with a cut-off at the heel only and the point of application of P_u is $\frac{5}{11}l'$ from the heel of the dam.

One important point brought out by Colman's investigation is that a cut-off to be effective in reducing upward pressure must be water-tight. Sheet piling as ordinarily driven is never water-tight and for this reason a good concrete cut-off of moderate depth will probably be more effective in preventing upward pressure than any amount of sheet piling.

Vacuum under Overfalling Sheet.—In case the water falling over a dam is contained between retaining walls at the ends of the dam in such a manner as to prevent the entrance of air along its downstream face, a vacuum will tend to form under the overfalling sheet of water. The effect of this action is to unbalance the atmospheric pressure on the two sides of the dam, or in other words, to increase the head on the upstream side. The amount of unbalanced pressure will be the pressure required to deflect the overfalling sheet of water from the path it would follow if air were freely admitted into a path conforming to the crest of the dam. In the extreme case the pressure against the upstream face of the dam will be increased by an amount equal to 34 feet of water. This difficulty may be over-

come by providing for the entrance of air, or by so designing the downstream face of the dam that there will be no space between it and the overfalling water.

Pressure on Curved Surfaces

Uniform Pressure on Cylindrical Surfaces.—Fig. 7 represents a cross-section of a pipe or cylinder subjected to a uniform internal hydrostatic pressure and Fig. 8 represents a similar cross-section subjected to a uniform external pressure. The pressure at each point on the circumference is normal to the surface as indicated by the arrows. The resultants of these

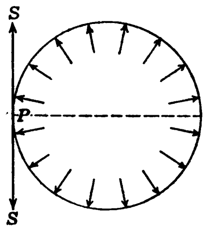


Fig. 7.

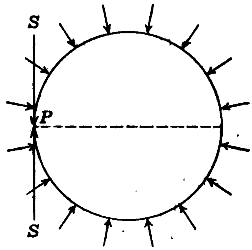


Fig. 8.

normal pressures, on opposite sides of any diameter, are equal and in opposite directions, and cause a stress in a direction tangent to the circumference. If S be the stress in pounds per linear inch, h the static head of water in feet and d the diameter of the pipe in inches,

$$S = \frac{1.3}{6} hd \tag{12}$$

S is tension for internal pressure and compression for external pressure.

Formula 12 may be used for computing the tension in pressure pipes where h (the head to the center of the pipe) is large as compared to d. Also for cylindrical tanks having a vertical axis, and for thin circular arch dams. This formula applies to a segment of a cylinder provided the edges are rigidly supported.

Uniform Pressure on Spherical Surfaces.—If S be the stress in pounds per linear inch on the surface of a sphere subjected

to uniform hydrostatic pressure, h the static head in feet and d the diameter of the sphere in inches,

$$S = \frac{1.3}{12} hd \tag{13}$$

S will be tension when the hydrostatic pressure is applied to the inner surface and compression when applied to the outer surface. The formula applies to segmental surfaces as well as complete spheres.

Non-uniform Pressure on Cylindrical Surfaces.—Let Fig. 9 represent a cross-section of a tank filled with water. The bottom of the tank is the segment of a cylinder. A horizontal section is rectangular. The tank is rigidly supported at the sides A and B. It is desired to find the tension S at any point P of the cylindrical surface.

Let W equal the weight of water per linear inch (parallel to axis of cylinder) on segment QP plus the weight of material in the segment. The radius to P makes an angle θ with the vertical. The tension per linear inch is given by the formula

$$S = \frac{W}{\sin \theta} \tag{14}$$

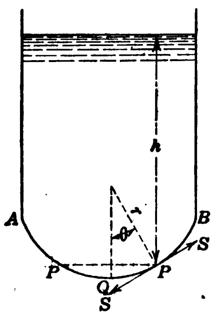


FIG. 9.

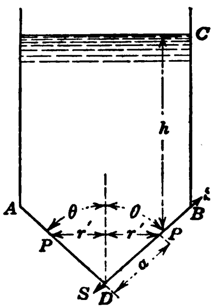


FIG. 10.

Non-uniform Pressure on Spherical Surfaces.—Fig. 9 may also represent a cross-section of a cylindrical water tank, with axis vertical, having a spherical bottom. In this case it may be necessary to determine the tension either along or at right angles to a meridional circumference of the sphere.

If S be the tension in pounds per linear inch along a meridional circumference (SS in figure), θ the angle of the cone subtended by the spherical segment PP, W' the total weight of water

above the segment plus the weight of the segment and r the radius of the sphere in inches.

$$S = \frac{W'}{2\pi r \sin^2 \theta} \tag{15}$$

If S' be the tension in pounds per linear inch across a meridional circumference (at right angles to SS), h the head of water in feet on P, and r the radius of the sphere in inches,

$$S' = \frac{1.3}{12} hr \tag{16}$$

Non-uniform Pressure on Conical Surfaces.—Fig. 10 represents a cross-section of a cylindrical tank with a conical bottom filled with water. At any point P there will be tension along the element of the cone and also at right angles to it.

If S be the tension in pounds per linear inch in the direction of an element of the cone (SS in figure), θ the angle which any element makes with the axis of the cone, W' the total weight of water above the segment of the cone whose base is the circle, intercepted by the horizontal plane through PP plus the weight of the segment, and r' the radius of the circle cut from the cone by this plane,

$$S = \frac{W'}{2\pi r' \cos \theta} \tag{17}$$

If S' be the tension in pounds per linear inch across an element of the cone, h the head of water in feet on P, θ the angle which any element makes with the axis of the cone and a the distance from the apex of the cone to P,

$$S' = \frac{1.3}{3} ha \tan \theta \tag{18}$$

From the above equation it is evident that S' will be a maximum when ha is maximum. It will be zero at D and if DB is less than BC the maximum value of S' will be at B.

In determining W or W' and other quantities in the foregoing equations it will be found more convenient to make a drawing from which the necessary dimensions may be approximately scaled. The results obtained in this manner will be sufficiently accurate for ordinary purposes.

In case the conditions of the problem are reversed and the pressures are applied to the opposite or convex sides of the surfaces the stresses will be equal in amount but will be compression instead of tension.

TABLE 9.—HYDROSTATIC PRESSURE IN POUNDS PER SQUARE FOOT FOR DIFFERENT HEADS

Weight of Water 62.4 Pounds per Cubic Foot

Head in feet	0	1	2	3	4	5	6	7	8	9
0	0	62	125	187	250	312	374	437	499	562
10	624	686	749	811	874	936	998	1,061	1,123	1,186
20	1,248	1,310	1,373	1,435	1,498	1,560	1,622	1,685	1,747	1,810
30	1,872	1,934	1,997	2,059	2,122	2,184	2,246	2,309	2,371	2,434
40	2,496	2,558	2,621	2,683	2,746	2,808	2,870	2,933	2,995	3,058
50	3,120	3,182	3,245	3,307	3,370	3,432	3,494	3,557	3,619	3,682
60	3,744	3,806	3,869	3,931	3,994	4,056	4,118	4,181	4,243	4,306
70	4,368	4,430	4,493	4,555	4,618	4,680	4,742	4,805	4,867	4,930
80	4,992	5,054	5,117	5,179	5,242	5,304	5,366	5,429	5,491	5,554
90	5,616	5,678	5,741	5,803	5,866	5,928	5,990	6,053	6,115	6,178
100	6,240	6,302	6,365	6,427	6,490	6,552	6,614	6,677	6,739	6,802
110	6,864	6,926	6,989	7,051	7,114	7,176	7,238	7,301	7,363	7,426
120	7,488	7,550	7,613	7,675	7,738	7,800	7,862	7,925	7,987	8,050
130	8,112	8,174	8,237	8,299	8,362	8,424	8,486	8,549	8,611	8,674
140	8,736	8,798	8,861	8,923	8,986	9,048	9,110	9,173	9,235	9,298
150	9,360	9,422	9,485	9,547	9,610	9,672	9,734	9,797	9,859	9,922
160	9,984	10,046	10,109	10,171	10,234	10,296	10,358	10,421	10,483	10,546
170	10,608	10,670	10,733	10,795	10,858	10,920	10,982	11,045	11,107	11,170
180	11,232	11,294	11,357	11,419	11,482	11,544	11,606	11,669	11,731	11,794
190	11,856	11,918	11,981	12,043	12,106	12,168	12,230	12,293	12,355	12,418
200	12,480	12,542	12,605	12,667	12,730	12,792	12,854	12,917	12,979	13,042
210	13,104	13,166	13,229	13,291	13,354	13,416	13,478	13,541	13,603	13,666
220	13,728	13,790	13,853	13,915	13,978	14,040	14,102	14,165	14,227	14,290
230	14,352	14,414	14,477	14,539	14,602	14,664	14,726	14,789	14,851	14,914
240	14,976	15,038	15,101	15,163	15,226	15,288	15,350	15,413	15,475	15,538
250	15,600	15,662	15,725	15,787	15,850	15,912	15,974	16,037	16,099	16,162
260	16,224	16,286	16,349	16,411	16,474	16,536	16,598	16,661	16,723	16,786
270	16,848	16,910	16,973	17,035	17,098	17,160	17,222	17,285	17,347	17,410
280	17,472	17,534	17,597	17,659	17,722	17,784	17,846	17,909	17,971	18,034
290	18,096	18,158	18,221	18,283	18,346	18,408	18,470	18,533	18,595	18,658
300	18,720	18,782	18,845	18,907	18,970	19,032	19,094	19,157	19,219	19,282
310	19,344	19,406	19,469	19,531	19,594	19,656	19,718	19,781	19,843	19,906
320	19,968	20,030	20,093	20,155	20,218	20,280	20,342	20,405	20,467	20,530
330	20,592	20,654	20,717	20,779	20,842	20,904	20,966	21,029	21,091	21,154
340	21,216	21,278	21,341	21,403	21,466	21,528	21,590	21,653	21,715	21,778
350	21,840	21,902	21,965	22,027	22,090	22,152	22,214	22,277	22,339	22,402
360	22,464	22,526	22,589	22,651	22,714	22,776	22,838	22,901	22,963	23,026
370	23,088	23,150	23,213	23,275	23,338	23,400	23,462	23,525	23,587	23,650
380	23,712	23,774	23,837	23,899	23,962	24,024	24,086	24,149	24,211	24,274
390	24,336	24,398	24,461	24,523	24,586	24,648	24,710	24,773	24,835	24,898
400	24,960	25,022	25,085	25,147	25,210	25,272	25,334	25,397	25,459	25,522
410	25,584	25,646	25,709	25,771	25,834	25,896	25,958	26,021	26,083	26,146
420	26,208	26,270	26,333	26,395	26,458	26,520	26,582	26,645	26,707	26,770
430	26,832	26,894	26,957	27,019	27,082	27,144	27,206	27,269	27,331	27,394
440	27,456	27,518	27,581	27,643	27,706	27,768	27,830	27,893	27,955	28,018
450	28,080	28,142	28,205	28,267	28,330	28,392	28,454	28,517	28,579	28,642
460	28,704	28,766	28,829	28,891	28,954	29,016	29,078	29,141	29,203	29,266
470	29,328	29,390	29,453	29,515	29,578	29,640	29,702	29,765	29,827	29,890
480	29,952	30,014	30,077	30,139	30,202	30,264	30,326	30,389	30,451	30,514
490	30,576	30,638	30,701	30,763	30,826	30,888	30,950	31,013	31,075	31,138

TABLE 10.—HYDROSTATIC PRESSURES IN POUNDS PER SQUARE INCH FOR DIFFERENT HEADS

Weight of Water 62.4 Pounds per Cubic Foot

Head in feet	0	1	2	3	4	5	6	7	8	9
0	0.00	0.04	0.09	0.13	0.17	0.22	0.26	0.30	0.35	0.39
1	0.43	0.48	0.52	0.56	0.61	0.65	0.69	0.74	0.78	0.82
2	0.87	0.91	0.95	1.00	1.04	1.08	1.13	1.17	1.21	1.26
3	1.30	1.34	1.39	1.43	1.47	1.52	1.56	1.60	1.65	1.69
4	1.73	1.78	1.82	1.86	1.91	1.95	1.99	2.04	2.08	2.12
5	2.17	2.21	2.25	2.30	2.34	2.38	2.43	2.47	2.51	2.56
6	2.60	2.64	2.69	2.73	2.77	2.82	2.86	2.90	2.95	2.99
7	3.03	3.08	3.12	3.16	3.21	3.25	3.29	3.34	3.38	3.42
8	3.47	3.51	3.55	3.60	3.64	3.68	3.73	3.77	3.81	3.86
9	3.90	3.94	3.99	4.03	4.07	4.12	4.16	4.20	4.25	4.29
10	4.33	4.38	4.42	4.46	4.51	4.55	4.59	4.64	4.68	4.72
11	4.77	4.81	4.85	4.90	4.94	4.98	5.03	5.07	5.11	5.16
12	5.20	5.24	5.29	5.33	5.37	5.42	5.46	5.50	5.55	5.59
13	5.63	5.68	5.72	5.76	5.81	5.85	5.89	5.94	5.98	6.02
14	6.07	6.11	6.15	6.20	6.24	6.28	6.33	6.37	6.41	6.46
15	6.50	6.54	6.59	6.63	6.67	6.72	6.76	6.80	6.85	6.89
16	6.93	6.98	7.02	7.06	7.11	7.15	7.19	7.24	7.28	7.32
17	7.37	7.41	7.45	7.50	7.54	7.58	7.63	7.67	7.71	7.76
18	7.80	7.84	7.89	7.93	7.97	8.02	8.06	8.10	8.15	8.19
19	8.23	8.28	8.32	8.36	8.41	8.45	8.49	8.54	8.58	8.62
20	8.67	8.71	8.75	8.80	8.84	8.88	8.93	8.97	9.01	9.06
21	9.10	9.14	9.19	9.23	9.27	9.32	9.36	9.40	9.45	9.49
22	9.53	9.58	9.62	9.66	9.71	9.75	9.79	9.84	9.88	9.92
23	9.97	10.01	10.05	10.10	10.14	10.18	10.23	10.27	10.31	10.36
24	10.40	10.44	10.49	10.53	10.57	10.62	10.66	10.70	10.75	10.79
25	10.83	10.88	10.92	10.96	11.01	11.05	11.09	11.14	11.18	11.22
26	11.27	11.31	11.35	11.40	11.44	11.48	11.53	11.57	11.61	11.66
27	11.70	11.74	11.79	11.83	11.87	11.92	11.96	12.00	12.05	12.09
28	12.13	12.18	12.22	12.26	12.31	12.35	12.39	12.44	12.48	12.52
29	12.57	12.61	12.65	12.70	12.74	12.78	12.83	12.87	12.91	12.96
30	13.00	13.04	13.09	13.13	13.17	13.22	13.26	13.30	13.35	13.39
31	13.43	13.48	13.52	13.56	13.61	13.65	13.69	13.74	13.78	13.82
32	13.87	13.91	13.95	14.00	14.04	14.08	14.13	14.17	14.21	14.26
33	14.30	14.34	14.39	14.43	14.47	14.52	14.56	14.60	14.65	14.69
34	14.73	14.78	14.82	14.86	14.91	14.95	14.99	15.04	15.08	15.12
35	15.17	15.21	15.25	15.30	15.34	15.38	15.43	15.47	15.51	15.56
36	15.60	15.64	15.69	15.73	15.77	15.82	15.86	15.90	15.95	15.99
37	16.03	16.08	16.12	16.16	16.21	16.25	16.29	16.34	16.38	16.42
38	16.47	16.51	16.55	16.60	16.64	16.68	16.73	16.77	16.81	16.86
39	16.90	16.94	16.99	17.03	17.07	17.12	17.16	17.20	17.25	17.29
40	17.33	17.38	17.42	17.46	17.51	17.55	17.59	17.64	17.68	17.72
41	17.77	17.81	17.85	17.90	17.94	17.98	18.03	18.07	18.11	18.16
42	18.20	18.24	18.29	18.33	18.37	18.42	18.46	18.50	18.55	18.59
43	18.63	18.68	18.72	18.76	18.81	18.85	18.89	18.94	18.98	19.02
44	19.07	19.11	19.15	19.20	19.24	19.28	19.33	19.37	19.41	19.46
45	19.50	19.54	19.59	19.63	19.67	19.72	19.76	19.80	19.85	19.89
46	19.93	19.98	20.02	20.06	20.11	20.15	20.19	20.24	20.28	20.32
47	20.37	20.41	20.45	20.50	20.54	20.58	20.63	20.67	20.71	20.76
48	20.80	20.84	20.89	20.93	20.97	21.02	21.06	21.10	21.15	21.19
49	21.23	21.28	21.32	21.36	21.41	21.45	21.49	21.54	21.58	21.62

Table 10 (*Continued*)

Hydrostatic Pressures in Pounds per Square Inch for Different Heads

Weight of Water 62.4 Pounds per Cubic Foot

Head in feet	0	1	2	3	4	5	6	7	8	9
50	21.67	21.71	21.75	21.80	21.84	21.88	21.93	21.97	22.01	22.06
51	22.10	22.14	22.19	22.23	22.27	22.32	22.36	22.40	22.45	22.49
52	22.53	22.58	22.62	22.66	22.71	22.75	22.79	22.84	22.88	22.92
53	22.97	23.01	23.05	23.10	23.14	23.18	23.23	23.27	23.31	23.36
54	23.40	23.44	23.49	23.53	23.57	23.62	23.66	23.70	23.75	23.79
55	23.83	23.88	23.92	23.96	24.01	24.05	24.09	24.14	24.18	24.22
56	24.27	24.31	24.35	24.40	24.44	24.48	24.53	24.57	24.61	24.66
57	24.70	24.74	24.79	24.83	24.87	24.92	24.96	25.00	25.05	25.09
58	25.13	25.18	25.22	25.26	25.31	25.35	25.39	25.44	25.48	25.52
59	25.57	25.61	25.65	25.70	25.74	25.78	25.83	25.87	25.91	25.96
60	26.00	26.04	26.09	26.13	26.17	26.22	26.26	26.30	26.35	26.39
61	26.43	26.48	26.52	26.56	26.61	26.65	26.69	26.74	26.78	26.82
62	26.87	26.91	26.95	27.00	27.04	27.08	27.13	27.17	27.21	27.26
63	27.30	27.34	27.39	27.43	27.47	27.52	27.56	27.60	27.65	27.69
64	27.73	27.78	27.82	27.86	27.91	27.95	27.99	28.04	28.08	28.12
65	28.17	28.21	28.25	28.30	28.34	28.38	28.43	28.47	28.51	28.56
66	28.60	28.64	28.69	28.73	28.77	28.82	28.86	28.90	28.95	28.99
67	29.03	29.08	29.12	29.16	29.21	29.25	29.29	29.34	29.38	29.42
68	29.47	29.51	29.55	29.60	29.64	29.68	29.73	29.77	29.81	29.86
69	29.90	29.94	29.99	30.03	30.07	30.12	30.16	30.20	30.25	30.29
70	30.33	30.38	30.42	30.46	30.51	30.55	30.59	30.64	30.68	30.72
71	30.77	30.81	30.85	30.90	30.94	30.98	31.03	31.07	31.11	31.16
72	31.20	31.24	31.29	31.33	31.37	31.42	31.46	31.50	31.55	31.59
73	31.63	31.68	31.72	31.76	31.81	31.85	31.89	31.94	31.98	32.02
74	32.07	32.11	32.15	33.20	32.24	32.28	32.33	32.37	32.41	32.46
75	32.50	32.54	32.59	32.63	32.67	32.72	32.76	32.80	32.85	32.89
76	32.93	32.98	33.02	33.06	33.11	33.15	33.19	33.24	33.28	33.32
77	33.37	33.41	33.45	33.50	33.54	33.58	33.63	33.67	33.71	33.76
78	33.80	33.84	33.89	33.93	33.97	34.02	34.06	34.10	34.15	34.19
79	34.23	34.28	34.32	34.36	34.41	34.45	34.49	34.54	34.58	34.62
80	34.67	34.71	34.75	34.80	34.84	34.88	34.93	34.97	35.01	35.06
81	35.10	35.14	35.19	35.23	35.27	35.32	35.36	35.40	35.45	35.49
82	35.53	35.58	35.62	35.66	35.71	35.75	35.79	35.84	35.88	35.92
83	35.97	36.01	36.05	36.10	36.14	36.18	36.23	36.27	36.31	36.36
84	36.40	36.44	36.49	36.53	36.57	36.62	36.66	36.70	36.75	36.79
85	36.83	36.88	36.92	36.96	37.01	37.05	37.09	37.14	37.18	37.22
86	37.27	37.31	37.35	37.40	37.44	37.48	37.53	37.57	37.61	37.66
87	37.70	37.74	37.79	37.83	37.87	37.92	37.96	38.00	38.05	38.09
88	38.13	38.18	38.22	38.26	38.31	38.35	38.39	38.44	38.48	38.52
89	38.57	38.61	38.65	38.70	38.74	38.78	38.83	38.87	38.91	38.96
90	39.00	39.04	39.09	39.13	39.17	39.22	39.26	39.30	39.35	39.39
91	39.43	39.48	39.52	39.56	39.61	39.65	39.69	39.74	39.78	39.82
92	39.87	39.91	39.95	40.00	40.04	40.08	40.13	40.17	40.21	40.26
93	40.30	40.34	30.39	40.43	40.47	40.52	40.56	40.60	40.65	40.69
94	40.73	40.78	40.82	40.86	40.91	40.95	40.99	41.04	41.08	41.12
95	41.17	41.21	41.25	41.30	41.34	41.38	41.43	41.47	41.51	41.56
96	41.60	41.64	41.69	41.73	41.77	41.82	41.86	41.90	41.95	41.99
97	42.03	42.08	42.12	42.16	42.21	42.25	42.29	42.34	42.38	42.42
98	42.47	42.51	42.55	42.60	42.64	42.68	42.73	42.77	42.81	42.86
99	42.90	42.94	42.99	43.03	43.07	43.12	43.16	43.20	43.25	43.29

Table 10 (*Continued*)

Hydrostatic Pressures in Pounds per Square Inch for Different Heads

Weight of Water 62.4 Pounds per Cubic Foot

Head in feet	0	1	2	3	4	5	6	7	8	9
100	43.33	43.38	43.42	43.46	43.51	43.55	43.59	43.64	43.68	43.72
101	43.77	43.81	43.85	43.90	43.94	43.98	44.03	44.07	44.11	44.16
102	44.20	44.24	44.29	44.33	44.37	44.42	44.46	44.50	44.55	44.59
103	44.63	44.68	44.72	44.76	44.81	44.85	44.89	44.94	44.98	45.02
104	45.07	45.11	45.15	45.20	45.24	45.28	45.33	45.37	45.41	45.46
105	45.50	45.54	45.59	45.63	45.67	45.72	45.76	45.80	45.85	45.89
106	45.93	45.98	46.02	46.06	46.11	46.15	46.19	46.24	46.28	46.32
107	46.37	46.41	46.45	46.50	46.54	46.58	46.63	46.67	46.71	46.76
108	46.80	46.84	46.89	46.93	46.97	47.02	47.06	47.10	47.15	47.19
109	47.23	47.28	47.32	47.36	47.41	47.45	47.49	47.54	47.58	47.62
110	47.67	47.71	47.75	47.80	47.84	47.88	47.93	47.97	48.01	48.06
111	48.10	48.14	48.19	48.23	48.27	48.32	48.36	48.40	48.45	48.49
112	48.53	48.58	48.62	48.66	48.71	48.75	48.79	48.84	48.88	48.92
113	48.97	49.01	49.05	49.10	49.14	49.18	49.23	49.27	49.31	49.36
114	49.40	49.44	49.49	49.53	49.57	49.62	49.66	49.70	49.75	49.79
115	49.83	49.88	49.92	49.96	50.01	50.05	50.09	50.14	50.18	50.22
116	50.27	50.31	50.35	50.40	50.44	50.48	50.53	50.57	50.61	50.66
117	50.70	50.74	50.79	50.83	50.87	50.92	50.96	51.00	51.05	51.09
118	51.13	51.18	51.22	51.26	51.31	51.35	51.39	51.44	51.48	51.52
119	51.57	51.61	51.65	51.70	51.74	51.78	51.83	51.87	51.91	51.96
120	52.00	52.04	52.09	52.13	52.17	52.22	52.26	52.30	52.35	52.39
121	52.43	52.48	52.52	52.56	52.61	52.65	52.69	52.74	52.78	52.82
122	52.87	52.91	52.95	53.00	53.04	53.08	53.13	53.17	53.21	53.26
123	53.30	53.34	53.39	53.43	53.47	53.52	53.56	53.60	53.65	53.69
124	53.73	53.78	53.82	53.86	53.91	53.95	53.99	54.04	54.08	54.12
125	54.17	54.21	54.25	54.30	54.34	54.38	54.43	54.47	54.51	54.56
126	54.60	54.64	54.69	54.73	54.77	54.82	54.86	54.90	54.95	54.99
127	55.03	55.08	55.12	55.16	55.21	55.25	55.29	55.34	55.38	55.42
128	55.47	55.51	55.55	55.60	55.64	55.68	55.73	55.77	55.81	55.86
129	55.90	55.94	55.99	56.03	56.07	56.12	56.16	56.20	56.25	56.29
130	56.33	56.38	56.42	56.46	56.51	56.55	56.59	56.64	56.68	56.72
131	56.77	56.81	56.85	56.90	56.94	56.98	57.03	57.07	57.11	57.16
132	57.20	57.24	57.29	57.33	57.37	57.42	57.46	57.50	57.55	57.59
133	57.63	57.68	57.72	57.76	57.81	57.85	57.89	57.94	57.98	58.02
134	58.07	58.11	58.15	58.20	58.24	58.28	58.33	58.37	58.41	58.46
135	58.50	58.54	58.59	58.63	58.67	58.72	58.76	58.80	58.85	58.89
136	58.93	58.98	59.02	59.06	59.11	59.15	59.19	59.24	59.28	59.32
137	59.37	59.41	59.45	59.50	59.54	59.58	59.63	59.67	59.71	59.76
138	59.80	59.84	59.89	59.93	59.97	60.02	60.06	60.10	60.15	60.19
139	60.23	60.28	60.32	60.36	60.41	60.45	60.49	60.54	60.58	60.62
140	60.67	60.71	60.75	60.80	60.84	60.88	60.93	60.97	61.01	61.06
141	61.10	61.14	61.19	61.23	61.27	61.32	61.36	61.40	61.45	61.49
142	61.53	16.58	61.62	61.66	61.71	61.75	61.79	61.84	61.88	61.92
143	61.97	62.01	62.05	62.10	62.14	62.18	62.23	62.27	62.31	62.36
144	62.40	62.44	62.49	62.53	62.57	62.62	62.66	62.70	62.75	62.79
145	62.83	62.88	62.92	62.96	63.01	63.05	63.09	63.14	63.18	63.22
146	63.27	63.31	63.35	63.40	63.44	63.48	63.53	63.57	63.61	63.66
147	63.70	63.74	63.79	63.83	63.87	63.92	63.96	64.00	64.05	64.09
148	64.13	64.18	64.22	64.26	64.31	64.35	64.39	64.44	64.48	64.52
149	64.57	64.61	64.65	64.70	64.74	64.78	64.83	64.87	64.91	64.96

TABLE 10 (*Continued*)

HYDROSTATIC PRESSURES IN POUNDS PER SQUARE INCH FOR DIFFERENT HEADS

Weight of Water 62.4 Pounds per Cubic Foot

Head in feet	0	1	2	3	4	5	6	7	8	9
150	65.00	65.04	65.09	65.13	65.17	65.22	65.26	65.30	65.35	65.39
151	65.43	65.48	65.52	65.56	65.61	65.65	65.69	65.74	65.78	65.82
152	65.87	65.91	65.95	66.00	66.04	66.08	66.13	66.17	66.21	66.26
153	66.30	66.34	66.39	66.43	66.47	66.52	66.56	66.60	66.65	66.69
154	66.73	66.78	66.82	66.86	66.91	66.95	66.99	67.04	67.08	67.12
155	67.17	67.21	67.25	67.30	67.34	67.38	67.43	67.47	67.51	67.56
156	67.60	67.64	67.69	67.73	67.77	67.82	67.86	67.90	67.95	67.99
157	68.03	68.08	68.12	68.16	68.21	68.25	68.29	68.34	68.38	68.42
158	68.47	68.51	68.55	68.60	68.64	68.68	68.73	68.77	68.81	68.86
159	68.90	68.94	68.99	69.03	69.07	69.12	69.16	69.20	69.25	69.29
160	69.33	69.38	69.42	69.46	69.51	69.55	69.59	69.64	69.68	69.72
161	69.77	69.81	69.85	69.90	69.94	69.98	70.03	70.07	70.11	70.16
162	70.20	70.24	70.29	70.33	70.37	70.42	70.46	70.50	70.55	70.59
163	70.63	70.68	70.72	70.76	70.81	70.85	70.89	70.94	70.98	71.02
164	71.07	71.11	71.15	71.20	71.24	71.28	71.33	71.37	71.41	71.46
165	71.50	71.54	71.59	71.63	71.67	71.72	71.76	71.80	71.85	71.89
166	71.93	71.98	72.02	72.06	72.11	72.15	72.19	72.24	72.28	72.32
167	72.37	72.41	72.45	72.50	72.54	72.58	72.63	72.67	72.71	72.76
168	72.80	72.84	72.89	72.93	72.97	73.02	73.06	73.10	73.15	73.19
169	73.23	73.28	73.32	73.36	73.41	73.45	73.49	73.54	73.58	73.62
170	73.67	73.71	73.75	73.80	73.84	73.88	73.93	73.97	74.01	74.06
171	74.10	74.14	74.19	74.23	74.27	74.32	74.36	74.40	74.45	74.49
172	74.53	74.58	74.62	74.66	74.71	74.75	74.79	74.84	74.88	74.92
173	74.97	75.01	75.05	75.10	75.14	75.18	75.23	75.27	75.31	75.36
174	75.40	75.44	75.49	75.53	75.57	75.62	75.66	75.70	75.75	75.79
175	75.83	75.88	75.92	75.96	76.01	76.05	76.09	76.14	76.18	76.22
176	76.27	76.31	76.35	76.40	76.44	76.48	76.53	76.57	76.61	76.66
177	76.70	76.74	76.79	76.83	76.87	76.92	76.96	77.00	77.05	77.09
178	77.13	77.18	77.22	77.26	77.31	77.35	77.39	77.44	77.48	77.52
179	77.57	77.61	77.65	77.70	77.74	77.78	77.83	77.87	77.91	77.96
180	78.00	78.04	78.09	78.13	78.17	78.22	78.26	78.30	78.35	78.39
181	78.43	78.48	78.52	78.56	78.61	78.65	78.69	78.74	78.78	78.82
182	78.87	78.91	78.95	79.00	79.04	79.08	79.13	79.17	79.21	79.26
183	79.30	79.34	79.39	79.43	79.47	79.52	79.56	79.60	79.65	79.69
184	79.73	79.78	79.82	79.86	79.91	79.95	79.99	80.04	80.08	80.12
185	80.17	80.21	80.25	80.30	80.34	80.38	80.43	80.47	80.51	80.56
186	80.60	80.64	80.69	80.73	80.77	80.82	80.86	80.90	80.95	80.99
187	81.03	81.08	81.12	81.16	81.21	81.25	81.29	81.34	81.38	81.42
188	81.47	81.51	81.55	81.60	81.64	81.68	81.73	81.77	81.81	81.86
189	81.90	81.94	81.99	82.03	82.07	82.12	82.16	82.20	82.25	82.29
190	82.33	82.38	82.42	82.46	82.51	82.55	82.59	82.64	82.68	82.72
191	82.77	82.81	82.85	82.90	82.94	82.98	83.03	83.07	83.11	83.16
192	83.20	83.24	83.29	83.33	83.37	83.42	83.46	83.50	83.55	83.59
193	83.63	83.68	83.72	83.76	83.81	83.85	83.89	83.94	83.98	84.02
194	84.07	84.11	84.15	84.20	84.24	84.28	84.33	84.37	84.41	84.46
195	84.50	84.54	84.59	84.63	84.67	84.72	84.76	84.80	84.85	84.89
196	84.93	84.98	85.02	85.06	85.11	85.15	85.19	85.24	85.28	85.32
197	85.37	85.41	85.45	85.50	85.54	85.58	85.63	85.67	85.71	85.76
198	85.80	85.84	85.89	85.93	85.97	86.02	86.06	86.10	86.15	86.19
199	86.23	86.28	86.32	86.36	86.41	86.45	86.49	86.54	86.58	86.62

Table 10 (*Concluded*)

Hydrostatic Pressures in Pounds per Square Inch for Different Heads

Weight of Water 62.4 Pounds per Cubic Foot

Head in feet	0	1	2	3	4	5	6	7	8	9
200	86.67	86.71	86.75	86.80	86.84	86.88	86.93	86.97	87.01	87.06
201	87.10	87.14	87.19	87.23	87.27	87.32	87.36	87.40	87.45	87.49
202	87.53	87.58	87.62	87.66	87.71	87.75	87.79	87.84	87.88	87.92
203	87.97	88.01	88.05	88.10	88.14	88.18	88.23	88.27	88.31	88.36
204	88.40	88.44	88.49	88.53	88.57	88.62	88.66	88.70	88.75	88.79
205	88.83	88.88	88.92	88.96	89.01	89.05	89.09	89.14	89.18	89.22
206	89.27	89.31	89.35	89.40	89.44	89.48	89.53	89.57	89.61	89.66
207	89.70	89.74	89.79	89.83	89.87	89.92	89.96	90.00	90.05	90.09
208	90.13	90.18	90.22	90.26	90.31	90.35	90.39	90.44	90.48	90.52
209	90.57	90.61	90.65	90.70	90.74	90.78	90.83	90.87	90.91	90.96
210	91.00	91.04	91.09	91.13	91.17	91.22	91.26	91.30	91.35	91.39
211	91.43	91.48	91.52	91.56	91.61	91.65	91.69	91.74	91.78	91.82
212	91.87	91.91	91.95	92.00	92.04	92.08	92.13	92.17	92.21	92.26
213	92.30	92.34	92.39	92.43	92.47	92.52	92.56	92.60	92.65	92.69
214	92.73	92.78	92.82	92.86	92.91	92.95	92.99	93.04	93.08	93.12
215	93.17	93.21	93.25	93.30	93.34	93.38	93.43	93.47	93.51	93.56
216	93.60	93.64	93.69	93.73	93.77	93.82	93.86	93.90	93.95	93.99
217	94.03	94.08	94.12	94.16	94.21	94.25	94.29	94.34	94.38	94.42
218	94.47	94.51	94.55	94.60	94.64	94.68	94.73	94.77	94.81	94.86
219	94.90	94.94	94.99	95.03	95.07	95.12	95.16	95.20	95.25	95.29
220	95.33	95.38	95.42	95.46	95.51	95.55	95.59	95.64	95.68	95.72
221	95.77	95.81	95.85	95.90	95.94	95.98	96.03	96.07	96.11	96.16
222	96.20	96.24	96.29	96.33	96.37	96.42	96.46	96.50	96.55	96.59
223	96.63	96.68	96.72	96.76	96.81	96.85	96.89	96.94	96.98	97.02
224	97.07	97.11	97.15	97.20	97.24	97.28	97.33	97.37	97.41	97.46
225	97.50	97.54	97.59	97.63	97.67	97.72	97.76	97.80	97.85	97.89
226	97.93	97.98	98.02	98.06	98.11	98.15	98.19	98.24	98.28	98.32
227	98.37	98.41	98.45	98.50	98.54	98.58	98.63	98.67	98.71	98.76
228	98.80	98.84	98.89	98.93	98.97	99.02	99.06	99.10	99.15	99.19
229	99.23	99.28	99.32	99.36	99.41	99.45	99.49	99.54	99.58	99.62
230	99.67	99.71	99.75	99.80	99.84	99.88	99.93	99.97	100.01	100.06
231	100.10	100.14	100.19	100.23	100.27	100.32	100.36	100.40	100.45	100.49
232	100.53	100.58	100.62	100.66	100.71	100.75	100.79	100.84	100.88	100.92
233	100.97	101.01	101.05	101.10	101.14	101.18	101.23	101.27	101.31	101.36
234	101.40	101.44	101.49	101.53	101.57	101.62	101.66	101.70	101.75	101.79
235	101.83	101.88	101.92	101.96	102.01	102.05	102.09	102.14	102.18	102.22
236	102.27	102.31	102.35	102.40	102.44	102.48	102.53	102.57	102.61	102.66
237	102.70	102.74	102.79	102.83	102.87	102.92	102.96	103.00	103.05	103.09
238	103.13	103.18	103.22	103.26	103.31	103.35	103.39	103.44	103.48	103.52
239	103.57	103.61	103.65	103.70	103.74	103.78	103.83	103.87	103.91	103.96
240	104.00	104.04	104.09	104.13	104.17	104.22	104.26	104.30	104.35	104.39
241	104.43	104.48	104.52	104.56	104.61	104.65	104.69	104.74	104.78	104.82
242	104.87	104.91	104.95	105.00	105.04	105.08	105.13	105.17	105.21	105.26
243	105.30	105.34	105.39	105.43	105.47	105.52	105.56	105.60	105.65	105.69
244	105.73	105.78	105.82	105.86	105.91	105.95	105.99	106.04	106.08	106.12
245	106.17	106.21	106.25	106.30	106.34	106.38	106.43	106.47	106.51	106.56
246	106.60	106.64	106.69	106.73	106.77	106.82	106.86	106.90	106.95	106.99
247	107.03	107.08	107.12	107.16	107.21	107.25	107.29	107.34	107.38	107.42
248	107.47	107.51	107.55	107.60	107.64	107.68	107.73	107.77	107.81	107.86
249	107.90	107.94	107.99	108.03	108.07	108.12	108.16	108.20	108.25	108.29

TABLE 11.—HEADS IN FEET CORRESPONDING TO DIFFERENT HYDROSTATIC PRESSURES IN POUNDS PER SQUARE INCH

Weight of Water 62.4 Pounds per Cubic Foot

Pressure in pounds per square inch	0	1	2	3	4	5	6	7	8	9
0	0.00	0.23	0.46	0.69	0.92	1.15	1.38	1.62	1.85	2.08
1	2.31	2.54	2.77	3.00	3.23	3.46	3.69	3.92	4.15	4.38
2	4.62	4.85	5.08	5.31	5.54	5.77	6.00	6.23	6.46	6.69
3	6.92	7.15	7.38	7.62	7.85	8.08	8.31	8.54	8.77	9.00
4	9.23	9.46	9.69	9.92	10.15	10.38	10.62	10.85	11.08	11.31
5	11.54	11.77	12.00	12.23	12.46	12.69	12.92	13.15	13.38	13.62
6	13.85	14.08	14.31	14.54	14.77	15.00	15.23	15.46	15.69	15.92
7	16.15	16.38	16.62	16.85	17.08	17.31	17.54	17.77	18.00	18.23
8	18.46	18.69	18.92	19.15	19.38	19.62	19.85	20.08	20.31	20.54
9	20.77	21.00	21.23	21.46	21.69	21.92	22.15	22.38	22.62	22.85
10	23.08	23.31	23.54	23.77	24.00	24.23	24.46	24.69	24.92	25.15
11	25.38	25.62	25.85	26.08	26.31	26.54	26.77	27.00	27.23	27.46
12	27.69	27.92	28.15	28.38	28.62	28.85	29.08	29.31	29.54	29.77
13	30.00	30.23	30.46	30.69	30.92	31.15	31.38	31.62	31.85	32.08
14	32.31	32.54	32.77	33.00	33.23	33.46	33.69	33.92	34.15	34.38
15	34.62	34.85	35.08	35.31	35.54	35.77	36.00	36.23	36.46	36.69
16	36.92	37.15	37.38	37.62	37.85	38.08	38.31	38.54	38.77	39.00
17	39.23	39.46	39.69	39.92	40.15	40.38	40.62	40.85	41.08	41.31
18	41.54	41.77	42.00	42.23	42.46	42.69	42.92	43.15	43.38	43.62
19	43.85	44.08	44.31	44.54	44.77	45.00	45.23	45.46	45.69	45.92
20	46.15	46.38	46.62	46.85	47.08	47.31	47.54	47.77	48.00	48.23
21	48.46	48.69	48.92	49.15	49.38	49.62	49.85	50.08	50.31	50.54
22	50.77	51.00	51.23	51.46	51.69	51.92	52.15	52.38	52.62	52.85
23	53.08	53.31	53.54	53.77	54.00	54.23	54.46	54.69	54.92	55.15
24	55.38	55.62	55.85	56.08	56.31	56.54	56.77	57.00	57.23	57.46
25	57.69	57.92	58.15	58.38	58.62	58.85	59.08	59.31	59.54	59.77
26	60.00	60.23	60.46	60.69	60.92	61.15	61.38	61.62	61.85	62.08
27	62.31	62.54	62.77	63.00	63.23	63.46	63.69	63.92	64.15	64.38
28	64.62	64.85	65.08	65.31	65.54	65.77	66.00	66.23	66.46	66.69
29	66.92	67.15	67.38	67.62	67.85	68.08	68.31	68.54	68.77	69.00
30	69.23	69.46	69.69	69.92	70.15	70.38	70.62	70.85	71.08	71.31
31	71.54	71.77	72.00	72.23	72.46	72.69	72.92	73.15	73.38	73.62
32	73.85	74.08	74.31	74.54	74.77	75.00	75.23	75.46	75.69	75.92
33	76.15	76.38	76.62	76.85	77.08	77.31	77.54	77.77	78.00	78.23
34	78.46	78.69	78.92	79.15	79.38	79.62	79.85	80.08	80.31	80.54
35	80.77	81.00	81.23	81.46	81.69	81.92	82.15	82.38	82.62	82.85
36	83.08	83.31	83.54	83.77	84.00	84.23	84.46	84.69	84.92	85.15
37	85.38	85.62	85.85	86.08	86.31	86.54	86.77	87.00	87.23	87.46
38	87.69	87.92	88.15	88.38	88.62	88.85	89.08	89.31	89.54	89.77
39	90.00	90.23	90.46	90.69	90.92	91.15	91.38	91.62	91.85	92.08
40	92.31	92.54	92.77	93.00	93.23	93.46	93.69	93.92	94.15	94.38
41	94.62	94.85	95.08	95.31	95.54	95.77	96.00	96.23	96.46	96.69
42	96.92	97.15	97.38	97.62	97.85	98.08	98.31	98.54	98.77	99.00
43	99.23	99.46	99.69	99.92	100.15	100.38	100.62	100.85	101.08	101.31
44	101.54	101.77	102.00	102.23	102.46	102.69	102.92	103.15	103.38	103.62
45	103.85	104.08	104.31	104.54	104.77	105.00	105.23	105.46	105.69	105.92
46	106.15	106.38	106.62	106.85	107.08	107.31	107.54	107.77	108.00	108.23
47	108.46	108.69	108.92	109.15	109.38	109.62	109.85	110.08	110.31	110.54
48	110.77	111.00	111.23	111.46	111.69	111.92	112.15	112.38	112.62	112.85
49	113.08	113.31	113.54	113.77	114.00	114.23	114.46	114.69	114.92	115.15

Table 11 (*Concluded*)

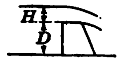
Heads in Feet Corresponding to Different Hydrostatic Pressures in Pounds per Square Inch

Weight of Water 62.4 Pounds per Cubic Foot

Pressure in pounds per square inch	0	1	2	3	4	5	6	7	8	9
50	115.38	115.62	115.85	116.08	116.31	116.54	116.77	117.00	117.23	117.46
51	117.69	117.92	118.15	118.38	118.62	118.85	119.08	119.31	119.54	119.77
52	120.00	120.23	120.46	120.69	120.92	121.15	121.38	121.62	121.85	122.08
53	122.31	122.54	122.77	123.00	123.23	123.46	123.69	123.92	124.15	124.38
54	124.62	124.85	125.08	125.31	125.54	125.77	126.00	126.23	126.46	126.69
55	126.92	127.15	127.38	127.62	127.85	128.08	128.31	128.54	128.77	129.00
56	129.23	129.46	129.69	129.92	130.15	130.38	130.62	130.85	131.08	131.31
57	131.54	131.77	132.00	132.23	132.46	132.69	132.92	133.15	133.38	133.62
58	133.85	134.08	134.31	134.54	134.77	135.00	135.23	135.46	135.69	135.92
59	136.15	136.38	136.62	136.85	137.08	137.31	137.54	137.77	138.00	138.23
60	138.46	138.69	138.92	139.15	139.38	139.62	139.85	140.08	140.31	140.54
61	140.77	141.00	141.23	141.46	141.69	141.92	142.15	142.38	142.62	142.85
62	143.08	143.31	143.54	143.77	144.00	144.23	144.46	144.69	144.92	145.15
63	145.38	145.62	145.85	146.08	146.31	146.54	146.77	147.00	147.23	147.46
64	147.69	147.92	148.15	148.38	148.62	148.85	149.08	149.31	149.54	149.77
65	150.00	150.23	150.46	150.69	150.92	151.15	151.38	151.62	151.85	152.08
66	152.31	152.54	152.77	153.00	153.23	153.46	153.69	153.92	154.15	154.38
67	154.62	154.85	155.08	155.31	155.54	155.77	156.00	156.23	156.46	156.69
68	156.92	157.15	157.38	157.62	157.85	158.08	158.31	158.54	158.77	159.00
69	159.23	159.46	159.69	159.92	160.15	160.38	160.62	160.85	161.08	161.31
70	161.54	161.77	162.00	162.23	162.46	162.69	162.92	163.15	163.38	163.62
71	163.85	164.08	164.31	164.54	164.77	165.00	165.23	165.46	165.69	165.92
72	166.15	166.38	166.62	166.85	167.08	167.31	167.54	167.77	168.00	168.23
73	168.46	168.69	168.92	169.15	169.38	169.62	169.85	170.08	170.31	170.54
74	170.77	171.00	171.23	171.46	171.69	171.92	172.15	172.38	172.62	172.85
75	173.08	173.31	173.54	173.77	174.00	174.23	174.46	174.69	174.92	175.15
76	175.38	175.62	175.85	176.08	176.31	176.54	176.77	177.00	177.23	177.46
77	177.69	177.92	178.15	178.38	178.62	178.85	179.08	179.31	179.54	179.77
78	180.00	180.23	180.46	180.69	180.92	181.15	181.38	181.62	181.85	182.08
79	182.31	182.54	182.77	183.00	183.23	183.46	183.69	183.92	184.15	184.38
80	184.62	184.85	185.08	185.31	185.54	185.77	186.00	186.23	186.46	186.69
81	186.92	187.15	187.38	187.62	187.85	188.08	188.31	188.54	188.77	189.00
82	189.23	189.46	189.69	189.92	190.15	190.38	190.62	190.85	191.08	191.31
83	191.54	191.77	192.00	192.23	192.46	192.69	192.92	193.15	193.38	193.62
84	193.85	194.08	194.31	194.54	194.77	195.00	195.23	195.46	195.69	195.92
85	196.15	196.38	196.62	196.85	197.08	197.31	197.54	197.77	198.00	198.23
86	198.46	198.69	198.92	199.15	199.38	199.62	199.85	200.08	200.31	200.54
87	200.77	201.00	201.23	201.46	201.69	201.92	202.15	202.38	202.62	202.85
88	203.08	203.31	203.54	203.77	204.00	204.23	204.46	204.69	204.92	205.15
89	205.38	205.62	205.85	206.08	206.31	206.54	206.77	207.00	207.23	207.46
90	207.69	207.92	208.15	208.38	208.62	208.85	209.08	209.31	209.54	209.77
91	210.00	210.23	210.46	210.69	210.92	211.15	211.38	211.62	211.85	212.08
92	212.31	212.54	212.77	213.00	213.23	213.46	213.69	213.92	214.15	214.38
93	214.62	214.85	215.08	215.31	215.54	215.77	216.00	216.23	216.46	216.69
94	216.92	217.15	217.38	217.62	217.85	218.08	218.31	218.54	218.77	219.00
95	219.23	219.46	219.69	219.92	220.15	220.38	220.62	220.85	221.08	221.31
96	221.54	221.77	222.00	222.23	222.46	222.69	222.92	223.15	223.38	223.62
97	223.85	224.08	224.31	224.54	224.77	225.00	225.23	225.46	225.69	225.92
98	226.15	226.38	226.62	226.85	227.08	227.31	227.54	227.77	228.00	228.23
99	228.46	228.69	228.92	229.15	229.38	229.62	229.85	230.08	230.31	230.54

TABLE 12.—TOTAL HORIZONTAL HYDROSTATIC PRESSURES IN POUNDS PER LINEAL FOOT FOR DAMS WITH OVERFLOW

D = Height of dam in feet
H = Depth of overflow in feet
P = Pressure in pounds per lineal foot
$P = 31.2\,(2DH + D^2)$.

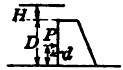


D in feet	H in feet									
	0	1	2	3	4	5	6	7	8	9
1	31	94	156	218	281	343	406	468	530	593
2	125	250	374	499	624	749	874	998	1,123	1,248
3	281	468	655	842	1,030	1,217	1,404	1,591	1,778	1,966
4	499	749	998	1,248	1,498	1,747	1,997	2,246	2,496	2,746
5	780	1,092	1,404	1,716	2,028	2,340	2,652	2,964	3,276	3,588
6	1,123	1,498	1,872	2,246	2,621	2,995	3,370	3,744	4,118	4,493
7	1,529	1,966	2,402	2,839	3,276	3,713	4,150	4,586	5,023	5,460
8	1,997	2,496	2,995	3,494	3,994	4,493	4,992	5,491	5,990	6,490
9	2,527	3,089	3,650	4,212	4,774	5,335	5,897	6,458	7,020	7,582
10	3,120	3,744	4,368	4,992	5,616	6,240	6,864	7,488	8,112	8,736
11	3,775	4,462	5,148	5,834	6,521	7,207	7,894	8,580	9,266	9,953
12	4,493	5,242	5,990	6,739	7,488	8,237	8,986	9,734	10,483	11,232
13	5,273	6,084	6,895	7,706	8,518	9,329	10,140	10,951	11,762	12,574
14	6,115	6,989	7,862	8,736	9,610	10,483	11,357	12,230	13,104	13,978
15	7,020	7,956	8,892	9,828	10,764	11,700	12,636	13,572	14,508	15,444
16	7,987	8,986	9,984	10,982	11,981	12,979	13,978	14,976	15,974	16,973
17	9,017	10,078	11,138	12,199	13,260	14,321	15,382	16,442	17,503	18,564
18	10,109	11,232	12,355	13,478	14,602	15,725	16,848	17,971	19,094	20,218
19	11,263	12,449	13,634	14,820	16,006	17,191	18,377	19,562	20,748	21,934
20	12,480	13,728	14,976	16,224	17,472	18,720	19,968	21,216	22,464	23,712
21	13,759	15,070	16,380	17,690	19,001	20,311	21,622	22,932	24,242	25,553
22	15,101	16,474	17,846	19,219	20,592	21,965	23,338	24,710	26,083	27,456
23	16,505	17,940	19,375	20,810	22,246	23,681	25,116	26,551	27,986	29,422
24	17,971	19,469	20,966	22,464	23,962	25,459	26,957	28,454	29,952	31,450
25	19,500	21,060	22,620	24,180	25,740	27,300	28,860	30,420	31,980	33,540
26	21,091	22,714	24,336	25,958	27,581	29,203	30,826	32,448	34,070	35,693
27	22,745	24,430	26,114	27,799	29,484	31,169	32,854	34,538	36,223	37,908
28	24,461	26,208	27,955	29,702	31,450	33,197	34,944	36 691	38,438	40,186
29	26,239	28,049	29,858	31,668	33,478	35,287	37,097	38,906	40,716	42,526
30	28,080	29,952	31,824	33,696	35,568	37,440	39,312	41,184	43,056	44,928
31	29,983	31,918	33,852	35,786	37,721	39,655	41,590	43,524	45,458	47,393
32	31,949	33,946	35,942	37,939	39,936	41,933	43,930	45,926	47,923	49,920
33	33,977	36,036	38,095	40,154	42,214	44,273	46,332	48,391	50,450	52,510
34	36,067	38,189	40,310	42,432	44,554	46,675	48,797	50,918	53,040	55,162
35	38,220	40,404	42,588	44,772	46,956	49,140	51,324	53,508	55,692	57,876
36	40,435	42,682	44,928	47,174	49,421	51,667	53,914	56,160	58,406	60,653
37	42,713	45,022	47,330	49,639	51,948	54,257	56,566	58,874	61,183	63,492
38	45,053	47,424	49,795	52,166	54,538	56,909	59,280	61,651	64,022	66,394
39	47,455	49,889	52,322	54,756	57,190	59,623	62,057	64,490	66,924	69,358
40	49,920	52,416	54,912	57,408	59,904	62,400	64,896	67,392	69,888	72,384
41	52,447	55,006	57,564	60,122	62,681	65,239	67,798	70,356	72,914	75,473
42	55,037	57,658	60,278	62,899	65,520	68,141	70,762	73,382	76,003	78,624
43	57,689	60,372	63,055	65,738	68,422	71,105	73,788	76,471	79,154	81,838
44	60,403	63,149	65,894	68,640	71,386	74,131	76,877	79,622	82,368	85,114
45	63,180	65,988	68,796	71,604	74,412	77,220	80,028	82,836	85,644	88,452
46	66,019	68,890	71,760	74,630	77,501	80,371	83,242	86,112	88,982	91,853
47	68,921	71,854	74,786	77,719	80,652	83,585	86,518	89,450	92,383	95,316
48	71,885	74,880	77,875	80,870	83,866	86,861	89,856	92,851	95,846	98,842
49	74,911	77,969	81,026	84,084	87,142	90,199	93,257	96,315	99,372	102,430
50	78,000	81,120	84,240	87,360	90,480	93,600	96,720	99,840	102,960	106,080

Table 13.—Vertical Distances Above Base to Centers of Horizontal Pressure for Dams with Overflow

D = height of dam in feet.
H = depth of overflow in feet.
d = distance above base in feet to center of pressure.

$$d = \frac{D}{3}\left(1 + \frac{H}{D + 2H}\right).$$



D in feet	H in feet: 0	1	2	3	4	5	6	7	8	9
1	.33	.44	.47	.48	.48	.48	.48	.49	.49	.49
2	.67	.83	.89	.92	.93	.94	.95	.96	.96	.97
3	1.00	1.20	1.29	1.33	1.36	1.38	1.40	1.41	1.42	1.43
4	1.33	1.56	1.67	1.73	1.78	1.81	1.83	1.85	1.87	1.88
5	1.67	1.90	2.04	2.12	2.18	2.22	2.25	2.28	2.30	2.32
6	2.00	2.25	2.40	2.50	2.57	2.62	2.67	2.70	2.73	2.75
7	2.33	2.59	2.76	2.87	2.96	3.02	3.07	3.11	3.14	3.17
8	2.67	2.93	3.11	3.24	3.33	3.41	3.47	3.52	3.56	3.59
9	3.00	3.27	3.46	3.60	3.71	3.79	3.86	3.91	3.96	4.00
10	3.33	3.61	3.81	3.96	4.07	4.17	4.24	4.31	4.36	4.40
11	3.67	3.95	4.16	4.31	4.44	4.54	4.62	4.69	4.75	4.80
12	4.00	4.29	4.50	4.67	4.80	4.91	5.00	5.08	5.14	5.20
13	4.33	4.62	4.84	5.02	5.16	5.28	5.37	5.46	5.53	5.59
14	4.67	4.96	5.19	5.37	5.52	5.64	5.74	5.83	5.91	5.98
15	5.00	5.29	5.53	5.71	5.87	6.00	6.11	6.21	6.29	6.36
16	5.33	5.63	5.87	6.06	6.22	6.36	6.48	6.58	6.67	6.75
17	5.67	5.96	6.21	6.41	6.57	6.71	6.85	6.95	7.04	7.12
18	6.00	6.30	6.55	6.75	6.92	7.07	7.20	7.31	7.41	7.50
19	6.33	6.63	6.88	7.09	7.27	7.43	7.56	7.68	7.78	7.87
20	6.67	6.97	7.22	7.44	7.62	7.78	7.92	8.05	8.15	8.25
21	7.00	7.30	7.56	7.78	7.97	8.13	8.27	8.40	8.51	8.62
22	7.33	7.64	7.90	8.12	8.31	8.48	8.63	8.76	8.88	8.98
23	7.67	7.97	8.23	8.46	8.66	8.83	8.98	9.12	9.24	9.35
24	8.00	8.31	8.57	8.80	9.00	9.18	9.33	9.47	9.60	9.71
25	8.33	8.64	8.91	9.14	9.34	9.52	9.68	9.83	9.96	10.08
26	8.67	8.98	9.24	9.48	9.69	9.87	10.04	10.18	10.32	10.44
27	9.00	9.31	9.58	9.82	10.03	10.22	10.38	10.54	10.67	10.80
28	9.33	9.64	9.92	10.16	10.37	10.56	10.73	10.89	11.03	11.16
29	9.67	9.98	10.25	10.50	10.71	10.91	11.08	11.24	11.38	11.52
30	10.00	10.31	10.59	10.83	11.05	11.25	11.43	11.59	11.74	11.88
31	10.33	10.65	10.92	11.17	11.39	11.59	11.78	11.94	12.09	12.23
32	10.67	10.98	11.26	11.51	11.73	11.94	12.12	12.29	12.44	12.59
33	11.00	11.31	11.59	11.85	12.07	12.28	12.47	12.64	12.80	12.94
34	11.33	11.65	11.93	12.18	12.41	12.62	12.81	12.99	13.15	13.29
35	11.67	11.98	12.26	12.52	12.75	12.96	13.16	13.33	13.50	13.65
36	12.00	12.32	12.60	12.86	13.09	13.30	13.50	13.68	13.85	14.00
37	12.33	12.65	12.93	13.19	13.43	13.65	13.84	14.03	14.19	14.35
38	12.67	12.98	13.27	13.53	13.77	13.99	14.19	14.37	14.54	14.70
39	13.00	13.32	13.60	13.87	14.11	14.33	14.53	14.72	14.89	15.05
40	13.33	13.65	13.94	14.20	14.44	14.67	14.87	15.06	15.24	15.40
41	13.67	13.98	14.27	14.54	14.78	15.01	15.21	15.41	15.58	15.75
42	14.00	14.32	14.61	14.88	15.12	15.35	15.56	15.75	15.93	16.10
43	14.33	14.65	14.94	15.21	15.46	15.69	15.90	16.09	16.28	16.45
44	14.67	14.99	15.28	15.55	15.79	16.02	16.24	16.44	16.62	16.80
45	15.00	15.32	15.61	15.88	16.13	16.36	16.58	16.78	16.97	17.14
46	15.33	15.65	15.95	16.22	16.47	16.70	16.92	17.12	17.31	17.49
47	15.67	15.99	16.28	16.55	16.81	17.04	17.26	17.46	17.66	17.84
48	16.00	16.32	16.62	16.89	17.14	17.38	17.60	17.81	18.00	18.18
49	16.33	16.65	16.95	17.22	17.48	17.72	17.94	18.15	18.34	18.53
50	16.67	16.99	17.28	17.56	17.82	18.06	18.28	18.49	18.69	18.87

TABLE 14.—THEORETICAL HORSEPOWER OF 1 CUBIC FOOT PER SECOND OF WATER, FOR HEADS FROM 0 TO 100 FEET

Head in feet	0	1	2	3	4	5	6	7	8	9
1	.113	.125	.136	.147	.159	.170	.182	.193	.204	.216
2	.227	.238	.250	.261	.272	.284	.295	.306	.318	.329
3	.340	.352	.363	.374	.386	.397	.408	.420	.431	.442
4	.454	.465	.477	.488	.499	.511	.522	.533	.545	.556
5	.567	.579	.590	.601	.613	.624	.635	.647	.658	.669
6	.681	.692	.703	.715	.726	.737	.749	.760	.771	.783
7	.794	.806	.817	.828	.840	.851	.862	.874	.885	.896
8	.908	.919	.930	.942	.953	.964	.976	.987	.998	1.010
9	1.021	1.032	1.044	1.055	1.066	1.078	1.089	1.101	1.112	1.123
10	1.135	1.146	1.157	1.169	1.180	1.191	1.203	1.214	1.225	1.237
11	1.248	1.259	1.271	1.282	1.293	1.305	1.316	1.327	1.339	1.350
12	1.361	1.373	1.384	1.395	1.407	1.418	1.430	1.441	1.452	1.464
13	1.475	1.486	1.498	1.509	1.520	1.532	1.543	1.554	1.566	1.577
14	1.588	1.600	1.611	1.622	1.634	1.645	1.656	1.668	1.679	1.690
15	1.702	1.713	1.725	1.736	1.747	1.759	1.770	1.781	1.793	1.804
16	1.815	1.827	1.838	1.849	1.861	1.872	1.883	1.895	1.906	1.917
17	1.929	1.940	1.951	1.963	1.974	1.985	1.997	2.008	2.019	2.031
18	2.042	2.054	2.065	2.076	2.088	2.099	2.110	2.122	2.133	2.144
19	2.156	2.167	2.178	2.190	2.201	2.212	2.224	2.235	2.246	2.258
20	2.269	2.280	2.292	2.303	2.314	2.326	2.337	2.349	2.360	2.371
21	2.383	2.394	2.405	2.417	2.428	2.439	2.451	2.462	2.473	2.485
22	2.496	2.507	2.519	2.530	2.541	2.553	2.564	2.575	2.587	2.598
23	2.609	2.621	2.632	2.643	2.655	2.666	2.678	2.689	2.700	2.712
24	2.723	2.734	2.746	2.757	2.768	2.780	2.791	2.802	2.814	2.825
25	2.836	2.848	2.859	2.870	2.882	2.893	2.904	2.916	2.927	2.938
26	2.950	2.961	2.973	2.984	2.995	3.007	3.018	3.029	3.041	3.052
27	3.063	3.075	3.086	3.097	3.109	3.120	3.131	3.143	3.154	3.165
28	3.177	3.188	3.199	3.211	3.222	3.233	3.245	3.256	3.267	3.279
29	3.290	3.302	3.313	3.324	3.336	3.347	3.358	3.370	3.381	3.392
30	3.404	3.415	3.426	3.438	3.449	3.460	3.472	3.483	3.494	3.506
31	3.517	3.528	3.540	3.551	3.562	3.574	3.585	3.597	3.608	3.619
32	3.631	3.642	3.653	3.665	3.676	3.687	3.699	3.710	3.721	3.733
33	3.744	3.755	3.767	3.778	3.789	3.801	3.812	3.823	3.835	3.846
34	3.857	3.869	3.880	3.891	3.903	3.914	3.926	3.937	3.948	3.960
35	3.971	3.982	3.994	4.005	4.016	4.028	4.039	4.050	4.062	4.073
36	4.084	4.096	4.107	4.118	4.130	4.141	4.152	4.164	4.175	4.186
37	4.198	4.209	4.221	4.232	4.243	4.255	4.266	4.277	4.289	4.300
38	4.311	4.323	4.334	4.345	4.357	4.368	4.379	4.391	4.402	4.413
39	4.425	4.436	4.447	4.459	4.470	4.481	4.493	4.504	4.515	4.527
40	4.538	4.550	4.561	4.572	4.584	4.595	4.606	4.618	4.629	4.640
41	4.652	4.663	4.674	4.686	4.697	4.708	4.720	4.731	4.742	4.754
42	4.765	4.776	4.788	4.799	4.810	4.822	4.833	4.845	4.856	4.867
43	4.879	4.890	4.901	4.913	4.924	4.935	4.947	4.958	4.969	4.981
44	4.992	5.003	5.015	5.026	5.037	5.049	5.060	5.071	5.083	5.094
45	5.105	5.117	5.128	5.139	5.151	5.162	5.174	5.185	5.196	5.208
46	5.219	5.230	5.242	5.253	5.264	5.276	5.287	5.298	5.310	5.321
47	5.332	5.344	5.355	5.366	5.378	5.389	5.400	5.412	5.423	5.434
48	5.446	5.457	5.469	5.480	5.491	5.503	5.514	5.525	5.537	5.548
49	5.559	5.571	5.582	5.593	5.605	5.616	5.627	5.639	5.650	5.661
50	5.673	5.684	5.695	5.707	5.718	5.729	5.741	5.752	5.763	5.775

TABLE 14 (*Concluded*)

THEORETICAL HORSEPOWER OF 1 CUBIC FOOT PER SECOND OF WATER, FOR HEADS FROM 0 TO 100 FEET

Head in feet	0	1	2	3	4	5	6	7	8	9
51	5.786	5.798	5.809	5.820	5.832	5.843	5.854	5.866	5.877	5.888
52	5.900	5.911	5.922	5.934	5.945	5.956	5.968	5.979	5.990	6.002
53	6.013	6.024	6.036	6.047	6.058	6.070	6.081	6.093	6.104	6.115
54	6.127	6.138	6.149	6.161	6.172	6.183	6.195	6.206	6.217	6.229
55	6.240	6.251	6.263	6.274	6.285	6.297	6.308	6.319	6.331	6.342
56	6.353	6.365	6.376	6.387	6.399	6.410	6.422	6.433	6.444	6.456
57	6.467	6.478	6.490	6.501	6.512	6.524	6.535	6.546	6.558	6.569
58	6.580	6.592	6.603	6.614	6.626	6.637	6.648	6.660	6.671	6.682
59	6.694	6.705	6.717	6.728	6.739	6.751	6.762	6.773	6.785	6.796
60	6.807	6.819	6.830	6.841	6.853	6.864	6.875	6.887	6.898	6.909
61	6.921	6.932	6.943	6.955	6.966	6.977	6.989	7.000	7.011	7.023
62	7.034	7.046	7.057	7.068	7.080	7.091	7.102	7.114	7.125	7.136
63	7.148	7.159	7.170	7.182	7.193	7.204	7.216	7.227	7.238	7.250
64	7.261	7.272	7.284	7.295	7.306	7.318	7.329	7.341	7.352	7.363
65	7.375	7.386	7.397	7.409	7.420	7.431	7.443	7.454	7.465	7.477
66	7.488	7.499	7.511	7.522	7.533	7.545	7.556	7.567	7.579	7.590
67	7.601	7.613	7.624	7.635	7.647	7.658	7.670	7.681	7.692	7.704
68	7.715	7.726	7.738	7.749	7.760	7.772	7.783	7.794	7.806	7.817
69	7.828	7.840	7.851	7.862	7.874	7.885	7.896	7.908	7.919	7.930
70	7.942	7.953	7.965	7.976	7.987	7.999	8.010	8.021	8.033	8.044
71	8.055	8.067	8.078	8.089	8.101	8.112	8.123	8.135	8.146	8.157
72	8.169	8.180	8.191	8.203	8.214	8.225	8.237	8.248	8.259	8.271
73	8.282	8.294	8.305	8.316	8.328	8.339	8.350	8.362	8.373	8.384
74	8.396	8.407	8.418	8.430	8.441	8.452	8.464	8.475	8.486	8.498
75	8.509	8.520	8.532	8.543	8.554	8.566	8.577	8.589	8.600	8.611
76	8.623	8.634	8.645	8.657	8.668	8.679	8.691	8.702	8.713	8.725
77	8.736	8.747	8.759	8.770	8.781	8.793	8.804	8.815	8.827	8.838
78	8.849	8.861	8.872	8.883	8.895	8.906	8.918	8.929	8.940	8.952
79	8.963	8.974	8.986	8.997	9.008	9.020	9.031	9.042	9.054	9.065
80	9.076	9.088	9.099	9.110	9.122	9.133	9.144	9.156	9.167	9.178
81	9.190	9.201	9.213	9.224	9.235	9.247	9.258	9.269	9.281	9.292
82	9.303	9.315	9.326	9.337	9.349	9.360	9.371	9.383	9.394	9.405
83	9.417	9.428	9.439	9.451	9.462	9.473	9.485	9.496	9.507	9.519
84	9.530	9.542	9.553	9.564	9.576	9.587	9.598	9.610	9.621	9.632
85	9.644	9.655	9.666	9.678	9.689	9.700	9.712	9.723	9.734	9.746
86	9.757	9.768	9.780	9.791	9.802	9.814	9.825	9.837	9.848	9.859
87	9.871	9.882	9.893	9.905	9.916	9.927	9.939	9.950	9.961	9.973
88	9.984	9.995	10.007	10.018	10.029	10.041	10.052	10.063	10.075	10.086
89	10.097	10.109	10.120	10.131	10.143	10.154	10.166	10.177	10.188	10.200
90	10.211	10.222	10.234	10.245	10.256	10.268	10.279	10.290	10.302	10.313
91	10.324	10.336	10.347	10.358	10.370	10.381	10.392	10.404	10.415	10.426
92	10.438	10.449	10.461	10.472	10.483	10.495	10.506	10.517	10.529	10.540
93	10.551	10.563	10.574	10.585	10.597	10.608	10.619	10.631	10.642	10.653
94	10.665	10.676	10.687	10.699	10.710	10.721	10.733	10.744	10.755	10.767
95	10.778	10.790	10.801	10.812	10.824	10.835	10.846	10.858	10.869	10.880
96	10.892	10.903	10.914	10.926	10.937	10.948	10.960	10.971	10.982	10.994
97	11.005	11.016	11.028	11.039	11.050	11.062	11.073	11.085	11.096	11.107
98	11.119	11.130	11.141	11.153	11.164	11.175	11.187	11.198	11.219	11.221
99	11.232	11.243	11.255	11.266	11.277	11.289	11.300	11.311	11.323	11.334
100	11.345	11.357	11.368	11.379	11.391	11.402	11.414	11.425	11.436	11.448

Table 15

Theoretical Kilowatts of 1 Cubic Foot per Second of Water for Heads from 0 to 100 Feet

Head in feet	0	1	2	3	4	5	6	7	8	9
1	.085	.093	.102	.110	.118	.127	.135	.144	.152	.161
2	.169	.178	.186	.195	.203	.212	.220	.229	.237	.245
3	.254	.262	.271	.279	.288	.296	.305	.313	.322	.330
4	.339	.347	.355	.364	.372	.381	.389	.398	.406	.415
5	.423	.432	.440	.449	.457	.466	.474	.482	.491	.499
6	.508	.516	.525	.533	.542	.550	.559	.567	.576	.584
7	.592	.601	.609	.618	.626	.635	.643	.652	.660	.669
8	.677	.686	.694	.702	.711	.719	.728	.736	.745	.753
9	.762	.770	.779	.787	.796	.804	.813	.821	.829	.838
10	.846	.855	.863	.872	.880	.889	.897	906	.914	.923
11	.931	.939	.948	.956	.965	.973	.982	.990	.999	1.007
12	1.016	1.024	1.033	1.041	1.049	1.058	1.066	1.075	1.083	1.092
13	1.100	1.109	1.117	1.126	1.134	1.143	1.151	1.160	1.168	1.176
14	1.185	1.193	1.202	1.210	1.219	1.227	1.236	1.244	1.253	1.261
15	1.270	1.278	1.286	1.295	1.303	1.312	1.320	1.329	1.337	1.346
16	1.354	1.363	1.371	1.380	1.388	1.397	1.405	1.413	1.422	1.430
17	1.439	1.447	1.456	1.464	1.473	1.481	1.490	1.498	1.507	1.515
18	1.523	1.532	1.540	1.549	1.557	1.566	1.574	1.583	1.591	1.600
19	1.608	1.617	1.625	1.633	1.642	1.650	1.659	1.667	1.676	1.684
20	1.693	1.701	1.710	1.718	1.727	1.735	1.744	1.752	1.760	1.769
21	1.777	1.786	1.794	1.803	1.811	1.820	1.828	1.837	1.845	1.854
22	1.862	1.870	1.879	1.887	1.896	1.904	1.913	1.921	1.930	1.938
23	1.947	1.955	1.964	1.972	1.981	1.989	1.997	2.006	2.014	2.023
24	2.031	2.040	2.048	2.057	2.065	2.074	2.082	2.091	2.099	2.107
25	2.116	2.124	2.133	2.141	2.150	2.158	2.167	2.175	2.184	2.192
26	2.201	2.209	2.217	2.226	2.234	2.243	2.251	2.260	2.268	2.277
27	2.285	2.294	2.302	2.311	2.319	2.328	2.336	2.344	2.353	2.361
28	2.370	2.378	2.387	2.395	2.404	2.412	2.421	2.429	2.438	2.446
29	2.454	2.463	2.471	2.480	2.488	2.497	2.505	2.514	2.522	2.531
30	2.539	2.548	2.556	2.565	2.573	2.581	2.590	2.598	2.607	2.615
31	2.624	2.632	2.641	2.649	2.658	2.666	2.675	2.683	2.691	2.700
32	2.708	2.717	2.725	2.734	2.742	2.751	2.759	2.768	2.776	2.785
33	2.793	2.801	2.810	2.818	2.827	2.835	2.844	2.852	2.861	2.869
34	2.878	2.886	2.895	2.903	2.912	2.920	2.928	2.937	2.945	2.954
35	2.962	2.971	2.979	2.988	2.996	3.005	3.013	3.022	3.030	3.038
36	3.047	3.055	3.064	3.072	3.081	3.089	3.098	3.106	3.115	3.123
37	3.132	3.140	3.148	3.157	3.165	3.174	3.182	3.191	3.199	3.208
38	3.216	3.225	3.233	3.242	3.250	3.259	3.267	3.275	3.284	3.292
39	3.301	3.309	3.318	3.326	3.335	3.343	3.352	3.360	3.369	3.377
40	3.385	3.394	3.402	3.411	3.419	3.428	3.436	3.445	3.453	3.462
41	3.470	3.479	3.487	3.496	3.504	3.512	3.521	3.529	3.538	3.546
42	3.555	3.563	3.572	3.580	3.589	3.597	3.606	3.614	3.622	3.631
43	3.639	3.648	3.656	3.665	3.673	3.682	3.690	3.699	3.707	3.716
44	3.724	3.732	3.741	3.749	3.758	3.766	3.775	3.783	3.792	3.800
45	3.809	3.817	3.826	3.834	3.843	3.851	3.859	3.868	3.876	3.885
46	3.893	3.902	3.910	3.919	3.927	3.936	3.944	3.953	3.961	3.969
47	3.978	3.986	3.995	4.003	4.012	4.020	4.029	4.037	4.046	4.054
48	4.063	4.071	4.080	4.088	4.096	4.105	4.113	4.122	4.130	4.139
49	4.147	4.156	4.164	4.173	4.181	4.190	4.198	4.206	4.215	4.223
50	4.232	4.240	4.249	4.257	4.266	4.274	4.283	4.291	4.300	4.308

Table 15 (*Concluded*)

Theoretical Kilowatts of 1 Cubic Foot per Second of Water for Heads from 0 to 100 Feet

Head in feet	0	1	2	3	4	5	6	7	8	9
51	4.316	4.325	4.333	4.342	4.350	4.359	4.367	4.376	4.384	4.393
52	4.401	4.410	4.418	4.427	4.435	4.443	4.452	4.460	4.469	4.477
53	4.486	4.494	4.503	4.511	4.520	4.528	4.537	4.545	4.553	4.562
54	4.570	4.579	4.587	4.596	4.604	4.613	4.621	4.630	4.638	4.647
55	4.655	4.664	4.672	4.680	4.689	4.697	4.706	4.714	4.723	4.731
56	4.740	4.748	4.757	4.765	4.774	4.782	4.790	4.799	4.807	4.816
57	4.824	4.833	4.841	4.850	4.858	4.867	4.875	4.884	4.892	4.900
58	4.909	4.917	4.926	4.934	4.943	4.951	4.960	4.968	4.977	4.985
59	4.994	5.002	5.011	5.019	5.027	5.036	5.044	5.053	5.061	5.070
60	5.078	5.087	5.095	5.104	5.112	5.121	5.129	5.137	5.146	5.154
61	5.163	5.171	5.180	5.188	5.197	5.205	5.214	5.222	5.231	5.239
62	5.247	5.256	5.264	5.273	5.281	5.290	5.298	5.307	5.315	5.324
63	5.332	5.341	5.349	5.358	5.366	5.374	5.383	5.391	5.400	5.408
64	5.417	5.425	5.434	5.442	5.451	5.459	5.468	5.476	5.484	5.493
65	5.501	5.510	5.518	5.527	5.535	5.544	5.552	5.561	5.569	5.578
66	5.586	5.595	5.603	5.611	5.620	5.628	5.637	5.645	5.654	5.662
67	5.671	5.679	5.688	5.696	5.705	5.713	5.721	5.730	5.738	5.747
68	5.755	5.764	5.772	5.781	5.789	5.798	5.806	5.815	5.823	5.831
69	5.840	5.848	5.857	5.865	5.874	5.882	5.891	5.899	5.908	5.916
70	5.925	5.933	5.942	5.950	5.958	5.967	5.975	5.984	5.992	6.001
71	6.009	6.018	6.026	6.035	6.043	6.052	6.060	6.068	6.077	6.085
72	6.094	6.102	6.111	6.119	6.128	6.136	6.145	6.153	6.162	6.170
73	6.179	6.187	6.195	6.204	6.212	6.221	6.229	6.238	6.246	6.255
74	6.263	6.272	6.280	6.289	6.297	6.305	6.314	6.322	6.331	6.339
75	6.348	6.356	6.365	6.373	6.382	6.390	6.399	6.407	6.415	6.424
76	6.432	6.441	6.449	6.458	6.466	6.475	6.483	6.492	6.500	6.509
77	6.517	6.526	6.534	6.542	6.551	6.559	6.568	6.576	6.585	6.593
78	6.602	6.610	6.619	6.627	6.636	6.644	6.652	6.661	6.669	6.678
79	6.686	6.695	6.703	6.712	6.720	6.729	6.737	6.746	6.754	6.763
80	6.771	6.779	6.788	6.796	6.805	6.813	6.822	6.830	6.839	6.847
81	6.856	6.864	6.873	6.881	6.889	6.898	6.906	6.915	6.923	6.932
82	6.940	6.949	6.957	6.966	6.974	6.983	6.991	6.999	7.008	7.016
83	7.025	7.033	7.042	7.050	7.059	7.067	7.076	7.084	7.093	7.101
84	7.110	7.118	7.126	7.135	7.143	7.152	7.160	7.169	7.177	7.186
85	7.194	7.203	7.211	7.220	7.228	7.236	7.245	7.253	7.262	7.270
86	7.279	7.287	7.296	7.304	7.313	7.321	7.330	7.338	7.346	7.355
87	7.363	7.372	7.380	7.389	7.397	7.406	7.414	7.423	7.431	7.440
88	7.448	7.457	7.465	7.473	7.482	7.490	7.499	7.507	7.516	7.524
89	7.533	7.541	7.550	7.558	7.567	7.575	7.583	7.592	7.600	7.609
90	7.617	7.626	7.634	7.643	7.651	7.660	7.668	7.677	7.685	7.694
91	7.702	7.710	7.719	7.727	7.736	7.744	7.753	7.761	7.770	7.778
92	7.787	7.795	7.804	7.812	7.820	7.829	7.837	7.846	7.854	7.863
93	7.871	7.880	7.888	7.897	7.905	7.914	7.922	7.930	7.939	7.947
94	7.956	7.964	7.973	7.981	7.990	7.998	8.007	8.015	8.024	8.032
95	8.041	8.049	8.057	8.066	8.074	8.083	8.091	8.100	8.108	8.117
96	8.125	8.134	8.142	8.151	8.159	8.167	8.176	8.184	8.193	8.201
97	8.210	8.218	8.227	8.235	8.244	8.252	8.261	8.269	8.278	8.286
98	8.294	8.303	8.311	8.320	8.328	8.337	8.345	8.354	8.362	8.371
99	8.379	8.388	8.396	8.404	8.413	8.421	8.430	8.438	8.447	8.455
100	8.464	8.472	8.481	8.489	8.498	8.506	8.514	8.523	8.531	8.540

CHAPTER III

ORIFICES

The following nomenclature will be used in discussing orifices:

L = Breadth of rectangular orifice in feet
M = Height of rectangular orifice in feet
d = Diameter of circular orifice in feet
a = Area of orifice in square feet
Q = Discharge in cubic feet per second
v = Mean velocity in feet per second
v_t = Theoretical mean velocity in feet per second
h = Head on center of orifice
g = Acceleration due to gravity = 32.16 approximately
C_v = Coefficient of velocity
C_c = Coefficient of contraction
C = Coefficient of discharge = C_vC_c.

Fundamental Considerations

Theoretical Velocity.—The theoretical velocity of water flowing through an orifice is, by *Torricelli's theorem,* the velocity acquired by a body falling freely *in vacuo* through a distance equal to the difference in elevation between the surface of the water and the elevation of the center of the orifice. It was the discovery of this great fundamental principle which lead to our modern development of the science of hydraulics. The Torricelli theorem may be expressed by the formula

$$v_t = \sqrt{2gh} \qquad (1)$$

or

$$h = \frac{v_t^2}{2g} \qquad (2)$$

Tables 16, 17, and 18, pages 48, 49, and 50, give values of v_t for heads ranging from 0 to 500 feet. Tables 19 and 20, pages 51 and 53 give theoretical heads for velocities ranging from 0 to 50 feet per second.

Contraction.—The area of cross-section of a jet is less than the area of the orifice from which it discharges. When a jet leaves an orifice it contracts to a smaller area, later expanding and becoming more or less irregular. The section of minimum area is called the *vena contracta.* Let AD, Fig. 11, represent a section of a side of a vessel containing water which passes through an orifice BC. The vena contracta is at E, a little over one diameter from the inner edge of the wall.

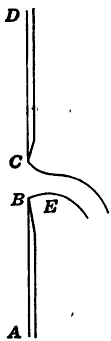


FIG. 11. Orifice.

The amount of contraction depends upon the form of the opening. Sharp corners at the inner edge of the orifice cause a maximum contraction and rounded corners conforming to the shape of a contracting jet cause the minimum contraction. There are various intermediate conditions.

The ratio of the area of the vena contracta to the area of the orifice is called the *coefficient of contraction,* C_c. Its mean value is approximately 0.62 for a sharp-edged orifice, and approaches unity for an orifice with rounded corners.

The discharge from an orifice is equal to the product of the area of a section of the jet at the vena contracta and the mean velocity, or

$$Q = C_c a v \tag{3}$$

The mean velocity of a jet is always slightly less than the theoretical velocity. The ratio of the mean velocity to the theoretical velocity is called the *coefficient of velocity,* C_v. The numerical value of C_v ranges between 0.96 and 0.99 with 0.98 a fair average value.

Equation (3) may be written

$$Q = C_c C_v a v_t \tag{4}$$

or

$$Q = C a v_t \tag{5}$$

or

$$Q = Ca\sqrt{2gh} \tag{6}$$

in which a is the area of the orifice and C the coefficient of discharge.

The coefficients of velocity and contraction are difficult to determine experimentally and are of theoretical rather than actical value. The coefficient of discharge may be determined

by measuring the quantity of water flowing from an orifice of known dimensions in a given time and determining the ratio between this discharge and the theoretical discharge. It is therefore the coefficient of discharge in which engineers are particularly interested. This coefficient has been found to vary with the head and the size of the orifice.

The sharp-edged orifice provides an accurate means of measuring small quantities of water. Orifices with rounded edges are frequently used in design and it is desirable to have coefficients of discharge for such orifices.

Rectangular Orifices.—In general the above discussion applies to an orifice of any shape. There is, however, a fundamental error in assuming that the head on the center of any

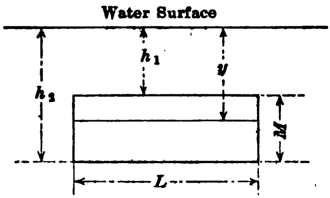


Fig. 12.—Rectangular orifice.

orifice, not horizontal, is the mean head. Referring to Fig. 12 the theoretical formula for discharge over a rectangular orifice may be derived as follows:

Let h_1 be the head on the upper edge of the orifice and h_2 the head on the lower edge. The discharge through any elementary strip of area Ldy at a distance y below the water surface is given by the equation

$$dQ = Ldy\sqrt{2gy}$$

which integrated between the limits h_2 and h_1 gives

$$Q = \tfrac{2}{3} L \sqrt{2g}\,(h_2^{3/2} - h_1^{3/2}) \tag{7}$$

When h_1 is zero this equation reduces to

$$Q = \tfrac{2}{3} \sqrt{2g}\, L\, h_2^{3/2} \tag{8}$$

which is the theoretical formula of discharge for a rectangular weir.

Equation (7) gives the theoretical discharge for a rectangular orifice. A similar though more complicated expression would give the theoretical discharge through circular orifices. The formula

$$Q = LM\sqrt{2gh} \tag{9}$$

in which h is the head on the center of the orifice, may be used without appreciable error unless h_1 is small as compared to M. For $h_1 = M$ equation (9) gives results about 1 per cent. too great and for $h_1 = 2M$ results are 0.3 per cent. too great.

Equation (9) is the base formula usually employed. Even for the lower heads the correction necessary may be made in applying the discharge coefficient. The actual working formula for discharge from a rectangular orifice, the same as for a circular orifice, or orifice of any other shape is, therefore,

$$Q = Ca\sqrt{2gh} \tag{10}$$

in which a is the area of the opening, C the coefficient of discharge and h the head on the center of the orifice.

Orifices with Full Contraction

Many experiments to determine the coefficients of discharge for sharp-edged orifices have been performed. Tables of coefficients of discharge for square and circular orifices, which have been quite generally accepted by modern hydraulicians were published by Hamilton Smith,[1] Jr., in 1886. These tables which were prepared with great care, are based upon experiments by Poncelet and Lebros, T. G. Ellis, Hamilton Smith, Jr., Julius Weisbach, W. C. Unwin, J. B. Francis, R. Steckel, Darcy and Bazin. Tables 21 and 22, pages 54 and 55, are reproductions of Smith's tables of coefficients of discharge through circular orifices and square orifices respectively.

Later experiments by Judd and King,[2] and Bilton[3] do not altogether confirm the results in Smith's tables. After a careful study of the earlier experiments in connection with his own and those by Judd and King, Bilton concludes:

1. The assumption that a coefficient of discharge common to all orifices from ½ inch to 12 inches in diameter is reached at a head of 100 feet is erroneous.

2. That in order to obtain complete and perfect contraction a certain minimum diameter and head are required. These

[1] Hamilton Smith, Jr.: Hydraulics, pp. 58–59.

[2] Horace Judd and Roy S. King: Some Experiments on the Frictionless Orifice. From paper read before the American Association for the Advancement of Science, July, 1906. *Engineering News*, Sept. 27, 1906.

[3] H. J. I. Bilton: Coefficients of Discharge through Circular Orifices. From paper read before the Victorian Institute of Engineers, April, 1908. *Engineering News*, July 9, 1908.

appear to be approximately 2½ inches and 17 inches respectively.

3. That orifices of 2½ inches diameter and over, under heads of 17 inches and over, have a common coefficient of discharge, lying between 0.59 and 0.60 but which is probably about 0.598 (subject to the head being not less than 2 or 3 diameters).

4. That in the case of orifices smaller than 2½ inches in diameter, contraction is never perfect and complete under any head, but is suppressed more and more as the diameter decreases, each size of orifice having its own constant or "normal" coefficient of discharge and its own critical head.

5. That as the diameter decreases, the normal coefficient increases, as also the critical head.

6. That in an infinitely small orifice, contraction is entirely suppressed and unity becomes the coefficient of discharge for all heads (subject to the effects of capillarity, cohesion, viscosity, temperature, etc.).

7. That the discharge of a circular orifice under any given head is the same, whether the jet be horizontal, vertical, or at any intermediate angle.

It is probable that with proper modification the above comments will apply to square or rectangular orifices. The approximate coefficient, 0.60 for orifices above 2½ inches in diameter and for heads greater than 17 inches, can be easily remembered.

A table of coefficients of discharge for rectangular orifices has been prepared by Fanning[1] from experiments by Michelotti, Bossut, Rennie, Castel, Lespinasse and Ellis. Fanning's results to three decimal places are given in Table 23, page 56. The coefficients given are for orifices 1 foot wide, and from 0.125 to 4 feet high under heads of from 0.3 to 50 feet.

Table 24, page 57, prepared by Bovey[2] from experiments on orifices of different shapes, having the same area as a circle ½ inch in diameter, gives the effect of shape of opening on the coefficient of discharge. It does not necessarily follow that a similar relation will hold for orifices of larger areas.

Orifices with Contractions Suppressed

Orifices with contractions either wholly or partially suppressed are not commonly used for measuring water because

[1] J. T. Fanning: Water Supply Engineering, pp. 205–206.

[2] Henry T. Bovey: Hydraulics, p. 40.

of the uncertainty which exists in selecting a proper coefficient of discharge. Such orifices, however, are often used in design and values of these coefficients are important. Unfortunately, available experimental data do not cover as wide a range of conditions as is desirable.

Table 25, page 58, has been prepared from results obtained by Smith[1] from experiments by Lebros. Though the orifices experimented upon were small, they should form a guide for selecting coefficients for larger orifices. It is probable that coefficients of discharge for orifices with contractions suppressed will decrease slightly as the size of the opening increases the same as for sharp-edged orifices. In Table 25 suppressed contraction means that the side of the channel coincides with the edge of the orifice and partly suppressed contraction means that the distance between the side of the channel and edge of the orifice is 0.066 foot.

Effects of Velocity of Approach

In the discussion thus far it has been assumed that water has been discharged from a reservoir which is large in comparison with the area of the orifice. When the area of the cross-section of the channel conducting water to the orifice is small compared to the area of the orifice, so that there is an appreciable velocity of approach, the discharge through the orifice will be increased.

There are but few experiments available on the effects of velocity of approach on the discharge through orifices. It has been customary to consider that the measured head should be increased by the velocity head due to the mean velocity in the channel of approach. This assumption would probably be approximately true if the velocity of approach were uniform. The velocity, however, is not uniform in all parts of the section and the kinetic energy of the water in the channel is greater[2] than it would be for uniform velocity. This conclusion is borne out by experiments on velocity of approach for weirs. The formula for discharge through any orifice with velocity of approach correction may be written.

$$Q = aC\sqrt{2g\left(h + \beta\frac{V^2}{2g}\right)} \tag{11}$$

[1] HAMILTON SMITH, JR.: Hydraulics, pp. 65–67.

[2] See discussion by ROBERT E. HORTON, *Water Supply and Irrigation Paper* No. 200, U. S. Geological Survey, pp. 17–20.

in which β is an empirical coefficient and V is the mean velocity of approach. Calling A the area of the channel of approach, since

$$V = \frac{Q}{A}$$

The equation may be written

$$Q = Ca\sqrt{2gh}\left(h + \frac{\beta}{2g}\cdot\frac{Q^2}{A^2}\right)^{\frac{1}{2}} \tag{12}$$

Reducing by a method analogous to that given on page 70 for weirs, the general formula for discharge from an orifice with velocity of approach becomes

$$Q = Ca\sqrt{2gh}\left(1 + \frac{C^2\beta}{2}\cdot\frac{a^2}{A^2}\right) \tag{13}$$

Experiments with orifices for determining β are not available but from experiments on sharp-crested weirs it appears to have a value of about 6.4, and assuming this value for sharp-edged orifices, the formula is

$$Q = Ca\sqrt{2gh}\left(1 + 3.2\,C^2\,\frac{a^2}{A^2}\right) \tag{14}$$

Short Tubes

Borda's mouthpiece is a short cylindrical tube projecting inwardly as shown in Fig. 13. The inward edge of the tube must be relatively thin and sharp to insure perfect contraction and its length must be such, about $\frac{1}{2}d$, that the jet will not touch the sides of the tube. The following are average coefficients.

$$C = 0.51, \qquad C_v = 0.98 \qquad C_c = 0.52$$

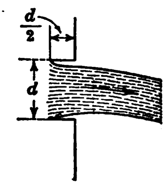


FIG. 13.—Borda's mouthpiece.

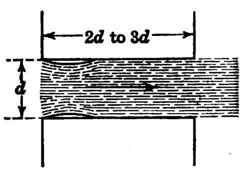


FIG. 14.—Standard short tube.

Standard Short Tubes.—A cylindrical tube, having a length of from 2 to 3 diameters with the inner end set flush with a flat wall so as to form a sharp-cornered entrance is commonly called a standard short tube. In such tubes, Fig. 14, the issuing jet touches the sides of the tube after leaving the

inner face and the tube flows full. The coefficient of contraction is considered unity. The coefficient of discharge varies from 0.78 to 0.83. The mean value generally used is

$$C = 0.82$$

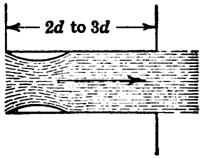


FIG. 15.—Short tube projecting inward.

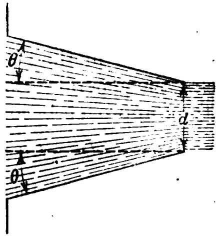


FIG. 16.—Convergent tube with sharp corner at entrance.

Short tubes projecting inward as shown in Fig. 15 have coefficients of discharge varying from 0 72 to 0.80. The average value commonly employed is

$$C = 0.75$$

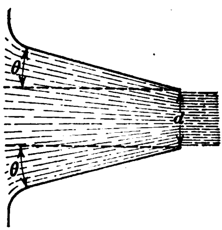


FIG. 17.—Convergent tube with rounded corner at entrance.

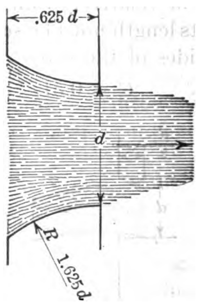


FIG. 18.—Converging bell-mouthed orifice.

Convergent short tubes are frustrums of cones as shown in Figs. 16 and 17. Fig. 16 has the larger base set flush with a flat wall so as to form a sharp-cornered entrance. Fig. 17 has the entrance to the tube slightly rounded. The sides of the tube make an angle θ with the axis of the cone.

Experiments for these tubes give conflicting results. Fair average values are given by Unwin[1] as follows:

Angle θ	0°	5¾°	11¼°	22½°	45°
C, for Fig. 16	0.83	0.94	0.92	0.85	
C, for Fig. 17	0.97	0.95	0.92	0.88	0.75

Converging Bell-mouthed Orifice.—If the surface of the opening is rounded to conform to the shape of the contracted jet, Fig. 18, C_c approaches unity. The following are coefficients by Weisbach[2] for d = 0.033 foot. Other experiments indicate that these results hold approximately for larger orifices.

h in feet	0.066	1.640	11.480	55.770	337.930
C	0.959	0.967	0.975	0.994	0.994

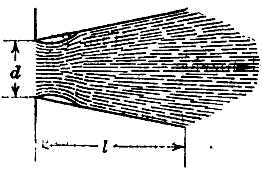


Fig. 19.—Diverging tube with sharp corner at entrance.

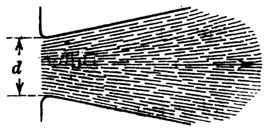


Fig. 20.—Diverging tube with rounded corner at entrance.

Diverging Conical Tubes.—Figs. 19 and 20. The coefficient of discharge varies with the angle of divergence and length of tube. Experiments by Venturi showed discharge to be a maximum with $l = 9d$, and angle of divergence equal to 5°. If divergence is not too great the tube will flow full. The coefficient of discharge is variable but when so designed that the tube flows full the following results may be obtained:

$$\text{For Fig. 19, } C = 1.4$$
$$\text{For Fig. 20, } C = 2.0$$

Nozzles.—A very complete set of experiments on the flow of water through nozzles was performed by Freeman[3] at Lowell, Mass., in 1888.

Two types of nozzles are in common use. Each are converging cones, one smooth throughout, Fig. 21, and the other with

[1] W. C. Unwin: Treatise on Hydraulics, p. 89.

[2] Julius Weisbach; Ingenieur und Machinen-Mechanik, p. 969 (ed. 1875).

[3] John R. Freeman: Experiments Relating to Hydraulics of Fire Streams, *Trans.* Amer. Soc. Civ. Eng., vol. 21, pp. 303–482.

a narrow ring at the outlet, Fig. 23. The opening in the ring nozzle is similar to a sharp-cornered orifice, which causes a contraction of the jet. The smooth nozzle may terminate in a cylinder, with the conical part curved as shown in Fig. 22. The ring nozzle was found by Freeman's experiments to have no particular advantage over smooth nozzles.

The following are mean values of coefficients of discharge of smooth nozzles as determined by Freeman:

Diameter in inches...	3/4	7/8	1	1 1/8	1 1/4	1 3/8
	0.983	0.982	0.972	0.976	0.971	0.959

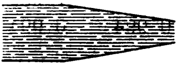


FIG. 21.

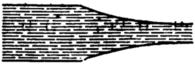


FIG. 22.

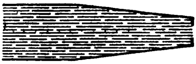


FIG. 23.

Different shaped nozzles.

The following are mean values of coefficients of discharge for ring nozzles as determined from Freeman's experiments. The ratio of the diameter of opening to diameter just back of ring is given.

Ratio	0.50	0.60	0.70	0.80	0.85	0.90	0.95	1.00
	0.630	0.650	0.680	0.710	0.730	0.770	0.870	0.975

Submerged Orifices

The discharge through submerged orifices is given by the formula

$$Q = Ca\sqrt{2gh} \tag{15}$$

where h is the difference in elevations of water surfaces above and below the orifice, C the coefficient of discharge and a the area of the opening. There are but few experiments available for determining C for submerged orifices. What data there are indicate that discharge coefficients are not greatly affected by submergence.

Table 26, page 59, gives coefficients of discharge for submerged sharp-edged orifices of various dimensions compiled from the best available data. Table 27, page 59, gives coefficients of discharge for an orifice 1 foot square with rounded edges, from experiments by Ellis.[1]

[1] *Trans.* Amer. Soc. Civ. Eng., vol. 5, p. 19

Gates

Gates Discharging Freely into Air.—The results of experiments on models of gates shown in the Figs. 24 and 25 are given by Unwin.[1] Table 28, page 60, giving coefficients of discharge for various depths of water above the top of the openings, was computed from Unwin's results. The head on

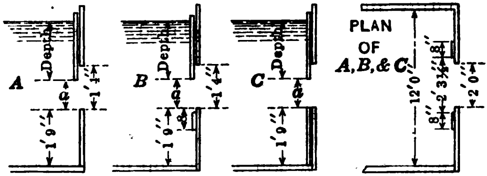


FIG. 24.—Gates discharging freely into air.

the center of orifice in this table may be obtained by adding half of the depth of opening to the depth of water above the top of orifice.

Determination of the coefficient of discharge of a sluice gate of the Argo dam at Ann Arbor, Mich., was made by Ward[2] in 1916. The gate is approximately 4 feet wide and 5 feet high. The opening is between concrete piers with beveled

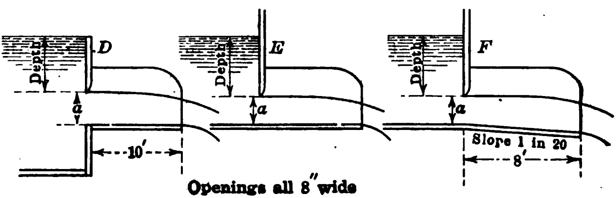


FIG. 25.—Gates with prolonged bottoms and sides.

noses. The gate closes on a base 1 foot above the concrete floor. The bottom of the gate formed the upper edge of the opening. Below the gate is a concrete basin 2.5 feet deep and 20 feet long. The water in the river below the dam when the test was made was lower than the gate sill. The mean head on the center of the opening was about 8 feet. For this head the mean of several observations gave a coefficient of discharge of 0.545.

[1] W. C. UNWIN: Hydraulics. Encyclopædia Britannica, 11th edition, vol. 14, p. 41.

[2] C. N. WARD: An unpublished thesis for the University of Michigan.

Submerged Gates.—Submerged gates are frequently encountered in engineering practice. They may be used for either intakes or sluices. Such gates are subject to a variety of entrance conditions which affect the contraction and consequently the coefficient of discharge. The most common case is where the bottom of the opening is nearly flush with the floor of the structure and the sides of the opening are flush with the piers in which the gate guides are placed. The contraction at the sides and bottom of the opening will then be greatly reduced. If the gate rests on a sill somewhat higher than the floor of the structure or if the gate guides project beyond the sides the amount of contraction will be increased. There is usually complete contraction at the top of the opening. The effect of contraction on such openings, however, appears to decrease as the size of the opening increases.

Only a few experiments on submerged gates are available and these are of a very general character. The problem is also complicated by the fact that a standing wave usually forms below the gate and there is a question as to the proper distance below the gate for measuring the water-surface elevation. The engineer is usually more interested in the elevation that occurs below the turbulence caused by the standing wave.

The experiments bearing on this subject have been discussed by Parker.[1] He analyzes experiments by Bornemann,[2] Chatterton[3] and Benton.[4] Chatterton gives the following formula for C for values of h below 5 feet.

$$C = 0.615 + 0.007 \times 2^{5-h} \tag{16}$$

Benton gives the following formula for heads below 5 feet and widths of gate opening (W) up to 10 feet:

$$C = 0.7201 + 0.0074\, W \tag{17}$$

Formulas (16) and (17) are based upon independent sets of observations. It will be observed that in formula (16) C varies only with h and in formula (17) it varies only with W. Results by the two formulas agree quite closely for heads of 1 foot or less but differ by from 10 to 25 per cent. for the higher heads. This divergence may be accounted for by the condi-

[1] PHILIP À MORLEY PARKER: Control of Water, pp. 164–168.

[2] *Civilingenieur*, vol. 26, p. 297.

[3] Hydraulic Experiments in the Kistna Delta. *Punjab Irrigation Branch Paper*, No. 8.

tions under which the experiments were performed. The conditions which will affect the discharge through submerged gates are explained below and these should be given careful consideration in each case before selecting a coefficient of discharge.

(*a*) The type of construction as affecting contraction. The greater the contraction the less the discharge.

(*b*) The condition of channels leading to and from the gate as affecting velocity of approach and velocity of retreat.

(*c*) The height of standing wave and point chosen for measuring elevation of water surface below the gate with reference to same. The discharge coefficient will be less when the head below the gate is measured in the trough of the standing wave than when measured farther downstream below all turbulence. The height of standing wave below the gate will increase as the depth of water decreases.

Table 29, page 61, gives values of the coefficient of discharge, C, computed from Chatterton's and Benton's formulas (formulas (16) and (17)).

Submerged Tubes.—Stewart[1] experimented on submerged tubes 4 feet square, with lengths varying from 0.31 to 14 feet, and heads from 0.05 to 0.30 feet. The entrance conditions included sharp edges and various degrees of suppressed contraction. Rogers and Smith have extended the experiments by Stewart to include sharp-edged tubes 6, 8, and 10 inches square, with varying lengths under heads up to 2.2 feet. Rogers and Smith[2] decided from their investigation that the coefficient of discharge C, varied as L/D, L being the length of tube and D the length of one side of the cross-section of the tube, and was independent of the head.

The author has prepared Table 30, page 62, from the results of these experiments assuming that the coefficient of discharge for any submerged tube varies as $\frac{L}{p}$, L and p being respectively the length of tube and perimeter of cross-section of the tube. For a square tube, $p = 4D$. It is evident that this assumption may be erroneous but it appears reasonable and as safe as any in view of the fact that there are no experimental data for circular or rectangular tubes.

[1] C. B. Stewart: Investigation of Flow through Large Submerged Orifices and Tubes. *Bulletin* of the University of Wisconsin, No. 216.

[2] T. C. Rogers and T. L. Smith: Experiments with Submerged Orifices and Tubes. *Engineering News*, Nov. 2, 1916.

TABLE 16.—THEORETICAL VELOCITIES IN FEET PER SECOND, FOR HEADS FROM 0 to 5 FEET. FROM THE FORMULA

$$v_t = \sqrt{2gh}$$

Head in feet	0	1	2	3	4	5	6	7	8	9
.0	0.00	0.80	1.13	1.39	1.60	1.79	1.96	2.12	2.27	2.41
.1	2.54	2.66	2.78	2.89	3.00	3.11	3.21	3.31	3.40	3.50
.2	3.59	3.68	3.76	3.85	3.93	4.01	4.09	4.17	4.24	4.32
.3	4.39	4.47	4.54	4.61	4.68	4.74	4.81	4.88	4.94	5.01
.4	5.07	5.14	5.20	5.26	5.32	5.38	5.44	5.50	5.56	5.61
.5	5.67	5.73	5.78	5.84	5.89	5.95	6.00	6.06	6.11	6.16
.6	6.21	6.26	6.31	6.37	6.42	6.47	6.52	6.56	6.61	6.66
.7	6.71	6.76	6.80	6.85	6.90	6.95	6.99	7.04	7.08	7.13
.8	7.17	7.22	7.26	7.31	7.35	7.39	7.44	7.48	7.52	7.57
.9	7.61	7.65	7.69	7.73	7.78	7.82	7.86	7.90	7.94	7.98
1.0	8.02	8.06	8.10	8.14	8.18	8.22	8.26	8.30	8.33	8.37
1.1	8.41	8.45	8.49	8.53	8.56	8.60	8.64	8.68	8.71	8.75
1.2	8.79	8.82	8.86	8.89	8.93	8.97	9.00	9.04	9.07	9.11
1.3	9.14	9.18	9.21	9.25	9.28	9.32	9.35	9.39	9.42	9.45
1.4	9.49	9.52	9.56	9.59	9.62	9.66	9.69	9.72	9.76	9.79
1.5	9.82	9.86	9.89	9.92	9.95	9.99	10.02	10.05	10.08	10.11
1.6	10.14	10.18	10.21	10.24	10.27	10.30	10.33	10.37	10.40	10.43
1.7	10.46	10.49	10.52	10.55	10.58	10.61	10.64	10.67	10.70	10.73
1.8	10.76	10.79	10.82	10.85	10.88	10.91	10.94	10.97	11.00	11.03
1.9	11.05	11.08	11.11	11.14	11.17	11.20	11.23	11.26	11.28	11.31
2.0	11.34	11.37	11.40	11.43	11.45	11.48	11.51	11.54	11.57	11.59
2.1	11.62	11.65	11.68	11.70	11.73	11.76	11.79	11.81	11.84	11.87
2.2	11.90	11.92	11.95	11.98	12.00	12.03	12.06	12.08	12.11	12.14
2.3	12.16	12.19	12.22	12.24	12.27	12.29	12.32	12.35	12.37	12.40
2.4	12.43	12.45	12.48	12.50	12.53	12.55	12.58	12.61	12.63	12.65
2.5	12.68	12.71	12.73	12.76	12.78	12.81	12.83	12.85	12.88	12.91
2.6	12.93	12.96	12.98	13.01	13.03	13.06	13.08	13.10	13.13	13.15
2.7	13.18	13.20	13.23	13.25	13.28	13.30	13.32	13.35	13.37	13.40
2.8	13.42	13.45	13.47	13.49	13.52	13.54	13.56	13.59	13.61	13.63
2.9	13.66	13.68	13.70	13.73	13.75	13.77	13.80	13.82	13.84	13.87
3.0	13.89	13.91	13.94	13.96	13.98	14.01	14.03	14.05	14.07	14.10
3.1	14.12	14.14	14.17	14.19	14.21	14.23	14.26	14.28	14.30	14.32
3.2	14.35	14.37	14.39	14.41	14.44	14.46	14.48	14.50	14.53	14.55
3.3	14.57	14.59	14.61	14.63	14.66	14.68	14.70	14.72	14.74	14.77
3.4	14.79	14.81	14.83	14.85	14.88	14.90	14.92	14.94	14.96	14.98
3.5	15.00	15.02	15.05	15.07	15.09	15.11	15.13	15.15	15.17	15.20
3.6	15.22	15.24	15.26	15.28	15.30	15.32	15.34	15.36	15.39	15.41
3.7	15.43	15.45	15.47	15.49	15.51	15.53	15.55	15.57	15.59	15.61
3.8	15.63	15.65	15.68	15.70	15.72	15.74	15.76	15.78	15.80	15.82
3.9	15.84	15.86	15.88	15.90	15.92	15.94	15.96	15.98	16.00	16.02
4.0	16.04	16.06	16.08	16.10	16.12	16.14	16.16	16.18	16.20	16.22
4.1	16.24	16.26	16.28	16.30	16.32	16.34	16.36	16.38	16.40	16.42
4.2	16.44	16.46	16.48	16.50	16.51	16.53	16.55	16.57	16.59	16.61
4.3	16.63	16.65	16.67	16.69	16.71	16.73	16.75	16.77	16.79	16.80
4.4	16.82	16.84	16.86	16.88	16.90	16.92	16.94	16.96	16.98	16.99
4.5	17.01	17.03	17.05	17.07	17.09	17.11	17.13	17.14	17.16	17.18
4.6	17.20	17.22	17.24	17.26	17.28	17.29	17.31	17.33	17.35	17.37
4.7	17.39	17.41	17.42	17.44	17.46	17.48	17.50	17.52	17.53	17.55
4.8	17.57	17.59	17.61	17.63	17.64	17.66	17.68	17.70	17.72	17.73
4.9	17.75	17.77	17.79	17.81	17.83	17.84	17.86	17.88	17.90	17.92

Table 17.—Theoretical Velocities in Feet per Second, for Heads from 0 to 50 Feet. From the Formula

$$v_t = \sqrt{2gh}$$

Head in feet	0		2	3	4	5	6	7	8	9
0	0.00	2.54	3.59	4.39	5.07	5.67	6.21	6.71	7.17	7.61
1	8.02	8.41	8.79	9.14	9.49	9.82	10.14	10.46	10.76	11.05
2	11.34	11.62	11.90	12.16	12.42	12.68	12.93	13.18	13.42	13.66
3	13.89	14.12	14.35	14.57	14.79	15.00	15.22	15.43	15.63	15.84
4	16.04	16.24	16.44	16.63	16.82	17.01	17.20	17.39	17.57	17.75
5	17.93	18.11	18.29	18.46	18.63	18.81	18.98	19.15	19.31	19.48
6	19.64	19.81	19.97	20.13	20.29	20.45	20.60	20.76	20.91	21.06
7	21.22	21.37	21.52	21.67	21.81	21.96	22.11	22.26	22.40	22.54
8	22.68	22.83	22.97	23.11	23.24	23.38	23.52	23.65	23.79	23.93
9	24.06	24.19	24.32	24.46	24.59	24.72	24.85	24.98	25.11	25.24
10	25.36	25.49	25.61	25.74	25.86	25.99	26.11	26.23	26.35	26.47
11	26.60	26.72	26.84	26.96	27.08	27.20	27.31	27.43	27.55	27.66
12	27.78	27.90	28.01	28.13	28.24	28.36	28.47	28.58	28.69	28.80
13	28.92	29.03	29.14	29.25	29.36	29.47	29.58	29.68	29.79	29.90
14	30.01	30.12	30.22	30.33	30.43	30.54	30.64	30.75	30.85	30.96
15	31.06	31.16	31.27	31.37	31.47	31.57	31.67	31.78	31.88	31.98
16	32.08	32.18	32.28	32.38	32.48	32.57	32.67	32.77	32.87	32.97
17	33.07	33.16	33.26	33.35	33.45	33.55	33.65	33.74	33.84	33.93
18	34.03	34.12	34.21	34.31	34.40	34.50	34.59	34.68	34.77	34.87
19	34.96	35.05	35.14	35.23	35.32	35.42	35.51	35.60	35.69	35.78
20	35.87	35.96	36.05	36.13	36.22	36.31	36.40	36.49	36.58	36.66
21	36.75	36.84	36.93	37.01	37.10	37.19	37.28	37.36	37.45	37.53
22	37.62	37.70	37.79	37.88	37.96	38.04	38.12	38.21	38.29	38.38
23	38.46	38.54	38.63	38.71	38.80	38.88	38.96	39.04	39.13	39.21
24	39.29	39.37	39.45	39.53	39.62	39.70	39.78	39.86	39.94	40.02
25	40.10	40.18	40.26	40.34	40.42	40.50	40.58	40.66	40.74	40.81
26	40.89	40.97	41.05	41.13	41.21	41.29	41.36	41.44	41.52	41.60
27	41.67	41.75	41.83	41.90	41.98	42.06	42.13	42.21	42.29	42.36
28	42.44	42.51	42.59	42.66	42.74	42.82	42.89	42.97	43.04	43.11
29	43.19	43.26	43.34	43.41	43.49	43.56	43.63	43.71	43.79	43.86
30	43.93	44.00	44.07	44.15	44.22	44.29	44.36	44.44	44.51	44.58
31	44.65	44.72	44.79	44.87	44.94	45.01	45.08	45.15	45.23	45.30
32	45.37	45.44	45.51	45.58	45.65	45.72	45.79	45.86	45.93	46.00
33	46.07	46.14	46.21	46.28	46.35	46.42	46.49	46.56	46.63	46.69
34	46.76	46.83	46.90	46.97	47.04	47.11	47.18	47.24	47.31	47.38
35	47.45	47.52	47.58	47.65	47.72	47.78	47.85	47.92	47.99	48.05
36	48.12	48.19	48.25	48.32	48.39	48.45	48.52	48.59	48.65	48.72
37	48.78	48.85	48.92	48.98	49.05	49.11	49.18	49.24	49.31	49.37
38	49.44	49.50	49.57	49.63	49.70	49.76	49.83	49.89	49.96	50.02
39	50.08	50.15	50.21	50.28	50.34	50.40	50.47	50.53	50.60	50.66
40	50.72	50.79	50.85	50.91	50.98	51.04	51.10	51.16	51.22	51.29
41	51.35	51.41	51 47	51.54	51.60	51.67	51.73	51.79	51.85	51.91
42	51.97	52.04	52 10	52.16	52.22	52.28	52.35	52.41	52.47	52.53
43	52.59	52.65	52.71	52.77	52.83	52.90	52.96	53.02	53.08	53.14
44	53.20	53.26	53.32	53.38	53.44	53.50	53.56	53.62	53.68	53.74
45	53.80	53.86	53.92	53.98	54.04	54.10	54.16	54.22	54.28	54.34
46	54.39	54.45	54.51	54.57	54.63	54.69	54.75	54.81	54.87	54.92
47	54.98	55.04	55.10	55.16	55.22	55.27	55.33	55.39	55.45	55.51
48	55.56	55.62	55.68	55.74	55.80	55.85	55.91	55.97	56.03	56.08
49	56.14	56.20	56.25	56.31	56.37	56.43	56.49	56.55	56.60	56.65

TABLE 18.—THEORETICAL VELOCITIES IN FEET PER SECOND, FOR HEADS FROM 0 TO 500 FEET. FROM THE FORMULA

$$v_t = \sqrt{2gh}$$

Head in feet	0.0	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0
00	0	8.02	11.34	13.89	16.04	17.93	19.64	21.22	22.68	24.06
10	25.36	26.60	27.78	28.92	30.01	31.06	32.08	33.07	34.03	34.96
20	35.87	36.75	37.62	38.46	39.29	40.10	40.89	41.67	42.44	43.19
30	43.93	44.65	45.37	46.07	46.76	47.45	48.12	48.78	49.44	50.08
40	50.72	51.35	51.97	52.59	53.20	53.80	54.39	54.98	55.56	56.14
50	56.71	57.27	57.83	58.39	58.93	59.48	60.02	60.55	61.08	61.60
60	62.12	62.64	63.15	63.66	64.16	64.66	65.15	65.65	66.13	66.62
70	67.10	67.58	68.05	68.52	68.99	69.46	69.92	70.38	70.83	71.28
80	71.73	72.18	72.62	73.06	73.50	73.94	74.37	74.80	75.23	75.66
90	76.08	76.51	76.93	77.34	77.76	78.17	78.58	78.99	79.39	79.80
100	80.20	80.60	81.00	81.39	81.79	82.18	82.57	82.96	83.35	83.73
110	84.11	84.50	84.88	85.25	85.63	86.00	86.38	86.75	87.12	87.49
120	87.85	88.22	88.58	88.95	89.31	89.67	90.02	90.38	90.74	91.09
130	91.44	91.79	92.14	92.49	92.84	93.18	93.53	93.87	94.21	94.55
140	94.89	95.23	95.57	95.91	96.24	96.57	96.91	97.24	97.57	97.90
150	98.22	98.55	98.88	99.20	99.53	99.85	100.17	100.49	100.81	101.13
160	101.45	101.77	102.08	102.39	102.71	103.02	103.33	103.64	103.95	104.26
170	104.57	104.87	105.18	105.49	105.79	106.10	106.40	106.70	107.00	107.30
180	107.60	107.90	108.20	108.49	108.79	109.08	109.37	109.67	109.96	110.26
190	110.55	110.84	111.13	111.42	111.71	112.00	112.28	112.57	112.85	113.14
200	113.42	113.70	113.99	114.27	114.55	114.83	115.11	115.39	115.67	115.94
210	116.22	116.50	116.77	117.05	117.32	117.60	117.87	118.14	118.42	118.69
220	118.96	119.23	119.49	119.76	120.03	120.30	120.57	120.83	121.10	121.36
230	121.63	121.89	122.16	122.42	122.68	122.94	123.21	123.47	123.73	123.99
240	124.25	124.50	124.76	125.02	125.28	125.53	125.79	126.04	126.30	126.55
250	126.81	127.06	127.31	127.57	127.82	128.07	128.32	128.57	128.82	129.07
260	129.32	129.57	129.82	130.06	130.31	130.56	130.80	131.05	131.29	131.54
270	131.78	132.03	132.27	132.51	132.76	133.00	133.24	133.48	133.72	133.96
280	134.20	134.44	134.68	134.92	135.16	135.39	135.63	135.87	136.10	136.34
290	136.58	136.81	137.05	137.28	137.51	137.75	137.98	138.22	138.45	138.68
300	138.91	139.14	139.37	139.60	139.83	140.06	140.29	140.52	140.75	140.98
310	141.21	141.43	141.66	141.89	142.12	142.34	142.57	142.79	143.02	143.24
320	143.47	143.69	143.91	144.14	144.36	144.58	144.80	145.03	145.25	145.47
330	145.69	145.91	146.13	146.35	146.57	146.79	147.01	147.23	147.45	147.66
340	147.88	148.10	148.32	148.53	148.75	148.96	149.18	149.40	149.61	149.83
350	150.04	150.25	150.47	150.68	150.90	151.11	151.32	151.53	151.75	151.96
360	152.17	152.38	152.59	152.80	153.01	153.22	153.43	153.64	153.85	154.06
370	154.27	154.48	154.69	154.89	155.10	155.31	155.51	155.72	155.93	156.13
380	156.34	156.54	156.75	156.95	157.16	157.36	157.57	157.77	157.98	158.18
390	158.38	158.59	158.79	158.99	159.19	159.39	159.60	159.80	160.00	160.20
400	160.40	160.60	160.80	161.00	161.20	161.40	161.60	161.80	162.00	162.19
410	162.39	162.59	162.79	162.99	163.18	163.38	163.58	163.77	163.97	164.17
420	164.36	164.56	164.75	164.95	165.14	165.34	165.53	165.73	165.92	166.11
430	166.31	166.50	166.69	166.88	167.08	167.27	167.46	167.66	167.85	168.04
440	168.23	168.42	168.61	168.80	168.99	169.18	169.37	169.56	169.75	169.94
450	170.13	170.32	170.51	170.70	170.88	171.07	171.26	171.45	171.64	171.82
460	172.01	172.20	172.38	172.57	172.76	172.94	173.13	173.31	173.50	173.69
470	173.87	174.05	174.24	174.42	174.61	174.79	174.98	175.16	175.35	175.53
480	175.71	175.89	176.08	176.26	176.44	176.62	176.80	176.99	177.17	177.35
490	177.53	177.71	177.89	178.07	178.25	178.43	178.61	178.79	178.97	179.15

TABLE 19.—THEORETICAL HEADS IN FEET CORRESPONDING TO VELOCITIES FROM 0 TO 10 FEET PER SECOND. FROM THE FORMULA $h_t = \frac{v^2}{2g}$

Velocity in feet per second	0	1	2	3	4	5	6	7	8	9
0.0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0001	0.0001
.1	.0002	.0002	.0002	.0003	.0003	.0003	.0004	.0004	.0005	.0006
.2	.0006	.0007	.0008	.0008	.0009	.0010	.0011	.0011	.0012	.0013
.3	.0014	.0015	.0016	.0017	.0018	.0019	.0020	.0021	.0022	.0024
.4	.0025	.0026	.0027	.0029	.0030	.0031	.0033	.0034	.0036	.0037
.5	.0039	.0040	.0042	.0044	.0045	.0047	.0049	.0051	.0052	.0054
.6	.0056	.0058	.0060	.0062	.0064	.0066	.0068	.0070	.0072	.0074
.7	.0076	.0078	.0081	.0083	.0085	.0087	.0090	.0092	.0095	.0097
.8	.0099	.0102	.0105	.0107	.0110	.0112	.0115	.0118	.0120	.0123
.9	.0126	.0129	.0132	.0134	.0137	.0140	.0143	.0146	.0149	.0152
1.0	.0155	.0159	.0162	.0165	.0168	.0171	.0175	.0178	.0181	.0185
1.1	.0188	.0192	.0195	.0199	.0202	.0206	.0209	.0213	.0216	.0220
1.2	.0224	.0228	.0231	.0235	.0239	.0243	.0247	.0251	.0255	.0259
1.3	.0263	.0267	.0271	.0275	.0279	.0283	.0288	.0292	.0296	.0300
1.4	.0305	.0309	.0313	.0318	.0322	.0327	.0331	.0336	.0341	.0345
1.5	.0350	.0354	.0359	.0364	.0369	.0374	.0378	.0383	.0388	.0393
1.6	.0398	.0403	.0408	.0413	.0418	.0423	.0428	.0434	.0439	.0444
1.7	.0449	.0455	.0460	.0465	.0471	.0476	.0482	.0487	.0493	.0498
1.8	.0504	.0509	.0515	.0521	.0526	.0532	.0538	.0544	.0549	.0555
1.9	.0561	.0567	.0573	.0579	.0585	.0591	.0597	.0603	.0609	.0616
2.0	.0622	.0628	.0634	.0641	.0647	.0653	.0660	.0666	.0673	.0679
2.1	.0686	.0692	.0699	.0705	.0712	.0719	.0725	.0732	.0739	.0746
2.2	.0752	.0759	.0766	.0773	.0780	.0787	.0794	.0801	.0808	.0815
2.3	.0822	.0830	.0837	.0844	.0851	.0859	.0866	.0873	.0881	.0888
2.4	.0895	.0903	.0910	.0918	.0926	.0933	.0941	.0948	.0956	.0964
2.5	.0972	.0979	.0987	.0995	.1003	.1011	.1019	.1027	.1035	.1043
2.6	.1051	.1059	.1067	.1075	.1084	.1092	.1100	.1108	.1117	.1125
2.7	.1133	.1142	.1150	.1159	.1167	.1176	.1184	.1193	.1201	.1210
2.8	.1219	.1228	.1236	.1245	.1254	.1263	.1272	.1281	.1290	.1299
2.9	.1308	.1317	.1326	.1335	.1344	.1353	.1362	.1371	.1381	.1390
3.0	.1399	.1409	.1418	.1427	.1437	.1446	.1456	.1465	.1475	.1484
3.1	.1494	.1504	.1513	.1523	.1533	.1543	.1552	.1562	.1572	.1582
3.2	.1592	.1602	.1612	.1622	.1632	.1642	.1652	.1662	.1673	.1683
3.3	.1693	.1703	.1714	.1724	.1734	.1745	.1755	.1766	.1776	.1787
3.4	.1797	.1808	.1818	.1829	.1840	.1850	.1861	.1872	.1883	.1894
3.5	.1904	.1915	.1926	.1937	.1948	.1959	.1970	.1981	.1992	.2004
3.6	.2015	.2026	.2037	.2049	.2060	.2071	.2083	.2094	.2105	.2117
3.7	.2128	.2140	.2151	.2163	.2175	.2186	.2198	.2210	.2221	.2233
3.8	.2245	.2257	.2269	.2280	.2292	.2304	.2316	.2328	.2340	.2352
3.9	.2365	.2377	.2389	.2401	.2413	.2426	.2438	.2450	.2463	.2475
4.0	.2487	.2500	.2512	.2525	.2537	.2550	.2563	.2575	.2588	.2601
4.1	.2613	.2626	.2639	.2652	.2665	.2677	.2690	.2703	.2716	.2729
4.2	.2742	.2755	.2769	.2782	.2795	.2808	.2821	.2835	.2848	.2861
4.3	.2875	.2888	.2901	.2915	.2928	.2942	.2955	.2969	.2982	.2996
4.4	.3010	.3023	.3037	.3051	.3065	.3079	.3092	.3106	.3120	.3134
4.5	.3148	.3162	.3176	.3190	.3204	.3218	.3233	.3247	.3261	.3275
4.6	.3290	.3304	.3318	.3333	.3347	.3362	.3376	.3390	.3405	.3420
4.7	.3434	.3449	.3463	.3478	.3493	.3508	.3522	.3537	.3552	.3567
4.8	.3582	.3597	.3612	.3627	.3642	.3657	.3672	.3687	.3702	.3717
4.9	.3733	.3748	.3763	.3779	.3794	.3809	.3825	.3840	.3856	.3871

TABLE 19 (*Concluded*)

THEORETICAL HEADS IN FEET CORRESPONDING TO VELOCITIES FROM 0 TO 10 FEET PER SECOND. FROM THE FORMULA $h_t = \frac{v^2}{2g}$

Velocity in feet per second	0	.1	.2	3	4	5	6	7	8	9
5.	0.3887	0.3902	0.3918	0.3934	0.3949	.03965	0.3981	0.3996	0.4012	0.4028
5.1	.4044	.4060	.4076	.4092	.4108	.4124	.4140	.4156	.4172	.4188
5.2	.4204	.4220	.4236	.4253	.4269	.4285	.4302	.4318	.4334	.4351
5.3	.4367	.4384	.4400	.4417	.4433	.4450	.4467	.4483	.4500	.4517
5.4	.4534	.4550	.4567	.4584	.4601	.4618	.4635	.4652	.4669	.4686
5.5	.4703	.4720	.4737	.4754	.4772	.4789	.4806	.4824	.4841	.4858
5.6	.4876	.4893	.4911	.4928	.4946	.4963	.4981	.4998	.5016	.5034
5.7	.5051	.5069	.5087	.5105	.5122	.5140	.5158	.5176	.5194	.5212
5.8	.5230	.5248	.5266	.5284	.5302	.5321	.5339	.5357	.5375	.5394
5.9	.5412	.5430	.5449	.5467	.5486	.5504	.5523	.5541	.5560	.5578
6.0	.5597	.5616	.5634	.5653	.5672	.5691	.5710	.5728	.5747	.5766
6.1	.5785	.5804	.5823	.5842	.5861	.5880	.5900	.5919	.5938	.5957
6.2	.5976	.5996	.6015	.6034	.6054	.6073	.6093	.6112	.6132	.6151
6.3	.6171	.6190	.6210	.6230	.6249	.6269	.6289	.6309	.6328	.6348
6.4	.6368	.6388	.6408	.6428	.6448	.6468	.6488	.6508	.6528	.6549
6.5	.6569	.6589	.6609	.6629	.6650	.6670	.6691	.6711	.6731	.6752
6.6	.6772	.6793	.6813	.6834	.6855	.6875	.6896	.6917	.6938	.6958
6.7	.6979	.7000	.7021	.7042	.7063	.7084	.7105	.7126	.7147	.7168
6.8	.7189	.7210	.7231	.7253	.7274	.7295	.7316	.7338	.7359	.7381
6.9	.7402	.7424	.7445	.7467	.7488	.7510	.7531	.7553	.7575	.7596
7.0	.7618	.7640	.7662	.7684	.7705	.7727	.7749	.7771	.7793	.7815
7.1	.7837	.7859	.7882	.7904	.7926	.7948	.7970	.7993	.8015	.8037
7.2	.8060	.8082	.8105	.8127	.8150	.8172	.8195	.8217	.8240	.8262
7.3	.8285	.8308	.8331	.8353	.8376	.8399	.8422	.8445	.8468	.8491
7.4	.8514	.8537	.8560	.8583	.8606	.8629	.8652	.8676	.8699	.8722
7.5	.8745	.8769	.8792	.8815	.8839	.8862	.8886	.8909	.8933	.8956
7.6	.8980	.9004	.9027	.9051	.9075	.9099	.9122	.9146	.9170	.9194
7.7	.9218	.9242	.9266	.9290	.9314	.9338	.9362	.9386	.9411	.9435
7.8	.9459	.9483	.9508	.9532	.9556	.9581	.9605	.9629	.9654	.9678
7.9	.9703	.9728	.9752	.9777	.9802	.9826	.9851	.9876	.9901	.9925
8.0	.9950	.9975	1.0000	1.0025	1.0050	1.0075	1.0100	1.0125	1.0150	1.0175
8.1	1.0201	1.0226	1.0251	1.0276	1.0302	1.0327	1.0352	1.0378	1.0403	1.0429
8.2	1.0454	1.0479	1.0505	1.0531	1.0556	1.0582	1.0608	1.0633	1.0659	1.0685
8.3	1.0711	1.0736	1.0762	1.0788	1.0814	1.0840	1.0866	1.0892	1.0918	1.0944
8.4	1.0970	1.0996	1.1022	1.1049	1.1075	1.1101	1.1127	1.1154	1.1180	1.1206
8.5	1.1233	1.1259	1.1286	1.1312	1.1339	1.1365	1.1392	1.1419	1.1445	1.1472
8.6	1.1499	1.1526	1.1552	1.1579	1.1606	1.1633	1.1660	1.1687	1.1714	1.1741
8.7	1.1768	1.1795	1.1822	1.1849	1.1876	1.1903	1.1931	1.1958	1.1985	1.2012
8.8	1.2040	1.2067	1.2095	1.2122	1.2150	1.2177	1.2205	1.2232	1.2260	1.2287
8.9	1.2315	1.2343	1.2370	1.2398	1.2426	1.2454	1.2482	1.2509	1.2537	1.2565
9.0	1.2593	1.2621	1.2649	1.2677	1.2705	1.2734	1.2762	1.2790	1.2818	1.2846
9.1	1.2875	1.2903	1.2931	1.2960	1.2988	1.3017	1.3045	1.3074	1.3102	1.3131
9.2	1.3159	1.3188	1.3216	1.3245	1.3274	1.3303	1.3331	1.3360	1.3389	1.3418
9.3	1.3447	1.3476	1.3505	1.3534	1.3563	1.3592	1.3621	1.3650	1.3679	1.3708
9.4	1.3738	1.3767	1.3796	1.3825	1.3855	1.3884	1.3913	1.3943	1.3972	1.4002
9.5	1.4031	1.4061	1.4091	1.4120	1.4150	1.4179	1.4209	1.4239	1.4269	1.4299
9.6	1.4328	1.4358	1.4388	1.4418	1.4448	1.4478	1.4508	1.4538	1.4568	1.4598
9.7	1.4628	1.4659	1.4689	1.4719	1.4749	1.4780	1.4810	1.4840	1.4871	1.4901
9.8	1.4932	1.4962	1.4993	1.5023	1.5054	1.5084	1.5115	1.5146	1.5176	1.5207
9.9	1.5238	1.5269	1.5300	1.5330	1.5361	1.5392	1.5423	1.5454	1.5485	1.5516

TABLE 20.—THEORETICAL HEADS IN FEET CORRESPONDI TO VELOCITIES FROM 0 TO 50 FEET PER SECOND.

FROM THE FORMULA $h_t = \dfrac{v^2}{2g}$

Velocity in feet per second	0	1	2	3	4	5	6	7	8	9
0	0.000	0.000	0.001	0.001	0.002	0.004	0.006	.008	0.010	0.0
1	.016	.019	.022	.026	.030	.035	.040	.045	.050	.0
2	.062	.069	.075	.082	.090	.097	.106	.113	.122	.1
3	.140	.149	.159	.169	.180	.190	.202	.213	.224	.2
4	.249	.261	.274	.288	.301	.315	.329	.343	.358	.3
5	.389	.404	.420	.437	.453	.470	.488	.505	.523	.5
6	.560	.579	.598	.617	.637	.657	.677	.698	.719	.7
7	.762	.784	.806	.828	.851	.874	.898	.922	.946	.9
8	.995	1.020	1.045	1.071	1.097	1.123	1.150	1.177	1.204	1.2
9	1.259	1.287	1.316	1.345	1.374	1.403	1.433	1.463	1.494	1.5
10	1.555	1.586	1.618	1.650	1.682	1.714	1.747	1.780	1.813	1.8
11	1.881	1.916	1.950	1.985	2.021	2.056	2.092	2.128	2.165	2.2
12	2.239	2.276	2.314	2.352	2.391	2.429	2.468	2.508	2.547	2.5
13	2.627	2.668	2.709	2.750	2.792	2.834	2.876	2.918	2.961	3.0
14	3.047	3.091	3.135	3.179	3.224	3.269	3.314	3.360	3.406	3.4
15	3.498	3.545	3.592	3.639	3.687	3.735	3.784	3.832	3.881	3.9
16	3.980	4.030	4.080	4.131	4.182	4.233	4.284	4.336	4.388	4.4
17	4.493	4.546	4.600	4.653	4.707	4.761	4.816	4.871	4.926	4.9
18	5.037	5.093	5.150	5.207	5.264	5.321	5.379	5.437	5.495	5.5
19	5.613	5.672	5.732	5.791	5.851	5.912	5.973	6.034	6.095	6.1
20	6.219	6.281	6.344	6.407	6.470	6.534	6.598	6.662	6.726	6.7
21	6.856	6.922	6.988	7.054	7.120	7.187	7.254	7.321	7.389	7.4
22	7.525	7.593	7.662	7.731	7.801	7.871	7.941	8.011	8.082	8.1
23	8.225	8.296	8.368	8.440	8.513	8.586	8.659	8.733	8.807	8.8
24	8.955	9.030	9.105	9.181	9.256	9.332	9.409	9.485	9.562	9.6
25	9.717	9.795	9.873	9.952	10.031	10.110	10.189	10.269	10.349	10.4
26	10.510	10.591	10.672	10.754	10.836	10.918	11.000	11.083	11.167	11.2
27	11.334	11.418	11.502	11.587	11.672	11.758	11.843	11.929	12.016	12.1
28	12.189	12.276	12.364	12.452	12.540	12.628	12.717	12.806	12.896	12.9
29	13.075	13.166	13.256	13.347	13.438	13.530	13.622	13.714	13.807	13.9
30	13.993	14.086	14.180	14.274	14.368	14.463	14.558	14.653	14.749	14.8
31	14.941	15.037	15.134	15.232	15.329	15.427	15.525	15.623	15.722	15.8
32	15.920	16.020	16.120	16.220	16.321	16.422	16.523	16.625	16.726	16.8
33	16.931	17.034	17.137	17.240	17.344	17.448	17.552	17.657	17.762	17.8
34	17.973	18.079	18.185	18.291	18.398	18.505	18.613	18.720	18.828	18.9
35	19.046	19.155	19.264	19.373	19.483	19.593	19.704	19.815	19.926	20.0
36	20.149	20.261	20.374	20.487	20.600	20.713	20.826	20.940	21.055	21.1
37	21.284	21.399	21.515	21.631	21.747	21.863	21.980	22.097	22.215	22.3
38	22.450	22.569	22.687	22.806	22.925	23.045	23.165	23.285	23.405	23.5
39	23.647	23.769	23.891	24.013	24.135	24.258	24.381	24.504	24.628	24.7
40	24.876	25.000	25.125	25.250	25.376	25.501	25.627	25.754	25.881	26.0
41	26.135	26.263	26.391	26.519	26.647	26.776	26.905	27.035	27.165	27.2
42	27.425	27.556	27.687	27.819	27.950	28.082	28.215	28.347	28.480	28.6
43	28.747	28.881	29.015	29.149	29.284	29.419	29.555	29.691	29.827	29.9
44	30.100	30.237	30.374	30.511	30.649	30.788	30.927	31.065	31.204	31.3
45	31.483	31.623	31.764	31.904	32.045	32.187	32.328	32.470	32.613	32.7
46	32.898	32.041	33.185	33.329	33.473	33.617	33.762	33.908	34.052	34.1
47	34.344	34.490	34.637	34.784	34.931	35.079	35.227	35.375	35.523	35.6
48	35.821	35.970	36.120	36.270	36.420	36.571	36.722	36.873	37.025	37.1
49	37.329	37.482	37.634	37.787	37.941	38.095	38.249	38.403	38.558	38.7

TABLE 21.—SMITH'S COEFFICIENTS OF DISCHARGE FOR VERTICAL CIRCULAR ORIFICES WITH FULL CONTRACTION

Head in feet, to center of orifice	Diameters in feet												
	.02	.03	.04	.05	.07	.10	.12	.15	.20	.40	.60	.80	1.00
.3?	....	....	....	.637	.628	.621	.613	.608					
.4	....	....	.637	.631	.624	.618	.612	.606					
.5	....	.643	.633	.627	.621	.615	.610	.605	.600	.596	.592		
.6	.655	.640	.630	.624	.618	.613	.609	.605	.601	.596	.593	.590	
.7	.651	.637	.628	.622	.616	.611	.607	.604	.601	.597	.594	.591	.590
.8	.648	.634	.626	.620	.615	.610	.606	.603	.601	.597	.594	.592	.591
.9	.646	.632	.624	.618	.613	.609	.605	.603	.601	.598	.595	.593	.591
1.0	.644	.631	.623	.617	.612	.608	.605	.603	.600	.598	.595	.593	.591
1.2	.641	.628	.620	.615	.610	.606	.604	.602	.600	.598	.596	.594	.592
1.4	.638	.625	.618	.613	.609	.605	.603	.601	.600	.599	.596	.594	.593
1.6	.636	.624	.617	.612	.608	.605	.602	.601	.600	.599	.597	.595	.594
1.8	.634	.622	.615	.611	.607	.604	.602	.601	.599	.599	.597	.595	.595
2.0	.632	.621	.614	.610	.607	.604	.601	.600	.599	.599	.597	.596	.595
2.5	.629	.619	.612	.608	.605	.603	.601	.600	.599	.599	.598	.597	.596
3.0	.627	.617	.611	.606	.604	.603	.601	.600	.599	.599	.598	.597	.597
3.5	.625	.616	.610	.606	.604	.602	.601	.600	.599	.599	.598	.597	.596
4.0	.623	.614	.609	.605	.603	.602	.600	.599	.599	.598	.597	.597	.596
5.0	.621	.613	.608	.605	.603	.601	.599	.599	.598	.598	.597	.596	.596
6.0	.618	.611	.607	.604	.602	.600	.599	.599	.598	.598	.597	.596	.596
7.0	.616	.609	.606	.603	.601	.600	.599	.599	.598	.598	.597	.596	.596
8.0	.614	.608	.605	.603	.601	.600	.599	.598	.598	.597	.596	.596	.596
9.0	.613	.607	.604	.602	.600	.599	.599	.598	.597	.597	.596	.596	.595
10.0	.611	.606	.603	.601	.599	.598	.598	.597	.597	.597	.596	.596	.595
20.0	.601	.600	.599	.598	.597	.596	.596	.596	.596	.596	.596	.595	.594
50.0?	.596	.596	.595	.595	.594	.594	.594	.594	.594	.594	.594	.593	.593
100.0?	.593	.593	.592	.592	.592	.592	.592	.592	.592	.592	.592	.592	.592

TABLE 22.—SMITH'S COEFFICIENTS OF DISCHARGE FOR VERTICAL SQUARE ORIFICES WITH FULL CONTRACTION

Head in feet to center of orifice	Length of side of square in feet												
	.02	.03	.04	.05	.07	.10	.12	.15	.20	.40	.60	.80	1.00
.3?	....	....	....	.642	.632	.624	.617	.612					
.4	....	....	.643	.637	.628	.621	.616	.611					
.5	....	.648	.639	.633	.625	.619	.614	.610	.605	.601	.597		
.6	.660	.645	.636	.630	.623	.617	.613	.610	.605	.601	.598	.596	
.7	.656	.642	.633	.628	.621	.616	.612	.609	.605	.602	.599	.598	.596
.8	.652	.639	.631	.625	.620	.615	.611	.608	.605	.602	.600	.598	.597
.9	.650	.637	.629	.623	.619	.614	.610	.608	.605	.603	.601	.599	.598
1.0	.648	.636	.628	.622	.618	.613	.610	.608	.605	.603	.601	.600	.599
1.2	.644	.633	.625	.620	.616	.611	.609	.607	.605	.604	.602	.601	.600
1.4	.642	.630	.623	.618	.614	.610	.608	.606	.605	.604	.602	.601	.601
1.6	.640	.628	.621	.617	.613	.609	.607	.606	.605	.605	.603	.602	.601
1.8	.638	.627	.620	.616	.612	.609	.607	.606	.605	.605	.603	.602	.602
2.0	.637	.626	.619	.615	612	.608	.606	.606	.605	.605	.604	.602	.602
2.5	.634	.624	.617	.613	.610	.607	.606	.606	.605	.605	.604	.603	.602
3.0	.632	.622	.616	.612	.609	.607	.606	.606	.605	.605	.604	.603	.603
3.5	.630	.621	.615	.611	.609	.607	.606	.605	.605	.605	.604	.603	.602
4.0	.628	.619	.614	.610	.608	.606	.606	.605	.605	.605	.603	.603	.602
5.0	.626	.617	.613	.610	.607	.606	.605	.605	.604	.604	.603	.602	.602
6.0	.623	.616	.612	.609	.607	.605	.605	.605	.604	.604	.603	.602	.602
7.0	.621	.615	.611	.608	.607	.605	.605	.604	.604	.604	.603	.602	.602
8.0	.619	.613	.610	.608	.606	.605	.604	.604	.604	.603	.603	.602	.602
9.0	.618	.612	.609	.607	.606	.604	.604	.604	.603	.603	.602	.602	.601
10.0	.616	.611	.608	.606	.605	.604	.604	.603	.603	.603	.602	.602	.601
20.0	.606	.605	.604	.603	.602	.602	.602	.602	.602	.601	.601	.601	.600
50.0?	.602	.601	.601	.601	.601	.600	.600	.600	.600	.600	.599	.599	.599
100.0?	.599	.598	.598	.598	.598	.598	.598	.598	.598	.598	.598	.598	.598

Table 23.—Fanning's Coefficients of Discharge for Vertical Rectangular Orifices, 1 *Foot Wide*, with Full Contraction. Head is Measured to Center of Orifice

Head in feet	Height of orifice in feet							
	0.125	0.25	0.5	0.75	1.0	1.5	2.0	4.0
.3	0.626							
.4	.625	.619						
.5	.624	.618	.615					
.6	.623	.618	.614					
.7	.623	.617	.613	.610				
.8	.622	.617	.612	.609				
.9	.622	.616	.612	.609	.605			
1.0	.622	.616	.611	.608	.605	.608		
1.25	.621	.615	.611	.608	.605	.607		
1.5	.620	.615	.610	.607	.604	.607	.609	
1.75	.619	.614	.610	.607	.604	.607	.609	
2.	.619	.614	.609	.606	.604	.606	.609	
2.25	.618	.613	.609	.606	.604	.606	.608	
2.5	.617	.613	.609	.606	.604	.606	.608	.610
2.75	.617	.612	.608	.605	.603	.606	.608	.610
3.	.616	.612	.608	.605	.603	.605	.607	.609
3.5	.615	.611	.607	.604	.603	.605	.607	.608
4.	.614	.610	.607	.604	.603	.604	.606	.608
4.5	.613	.610	.606	.603	.602	.604	.606	.607
5.	.612	.609	.605	.603	.602	.604	.605	.606
6.	.610	.608	.604	.602	.601	.603	.604	.605
7.	.609	.607	.604	.602	.601	.602	.603	.605
8.	.608	.606	.603	.601	.601	.602	.603	.604
9.	.607	.605	.602	.601	.601	.601	.602	.603
10.	.606	.604	.602	.601	.601	.601	.602	.603
15.	.607	.603	.601	.601	.601	.601	.602	.603
20.	.607	.604	.602	.601	.601	.601	.602	.603
25.	.608	.604	.602	.602	.601	.601	.603	.604
30.	.609	.604	.603	.602	.601	.602	.603	.605
35.	.610	.605	.603	.602	.601	.602	.604	.606
40.	.611	.606	.604	.603	.602	.603	.605	.607
50.	.614	.607	.605	.604	.602	.603	.606	.609

TABLE 24.—COEFFICIENTS OF DISCHARGE BY BOVEY, FOR VARIOUS SHAPED SHARP-EDGED ORIFICES WITH COMPLETE CONTRACTION. THIS TABLE INDICATES THE EFFECT OF THE SHAPE OF ORIFICES ON THE COEFFICIENT OF DISCHARGE. THE AREA OF ORIFICE IN EACH CASE WAS 0.196 SQUARE INCHES

Head in feet to center of orifice	Form of orifice							
	Circular	Square		Rectangular, ratio of sides 4:1		Rectangular, ratio of sides 10:1		Triangular
		Sides vertical	Diagonal vertical	Long sides vertical	Long sides horizontal	Long sides vertical	Long sides horizontal	
1	.620	.627	.628	.642	.643	.663	.664	.636
2	.613	.620	.628	.634	.636	.650	.651	.628
4	.608	.616	.618	.628	.629	.641	.642	.623
6	.607	.614	.616	.626	.627	.637	.637	.620
8	.606	.613	.614	.623	.625	.634	.635	.619
10	.605	.612	.613	.622	.624	.632	.633	.618
12	.604	.611	.612	.622	.623	.631	.631	.618
14	.604	.610	.612	.621	.622	.630	.630	.618
16	.603	.610	.611	.620	.622	.630	.630	.617
18	.603	.610	.611	.620	.621	.630	.629	.616
20	.603	.609	.611	.620	.621	.629	.628	.616

TABLE 25.—COEFFICIENTS OF DISCHARGE FOR RECTANGULAR ORIFICES WITH PARTIALLY SUPPRESSED CONTRACTIONS

Description of contraction	Dimensions of orifice in feet	Head in feet		
		1	3	5
	Hor. Vert.			
Complete contraction	.656 by .656	.598	.604	.603
	.328	.616	.615	.611
	.164	.631	.627	.620
	.098	.632	.628	.623
	.033	.652	.634	.620
Suppressed at bottom only	.656 by .656	.620	.624	.625
	.328	.649	.647	.643
	.164	.671	.668	.666
	098	.680	.677	.677
	.033	.710	.705	.696
Suppressed on both sides only	.656 by .656	.632	.628	.628
	.328	.637	.630	.630
	.164	.641	.634	.635
	.098	.653	.643	.639
	.033	.682	.667	.655
Suppressed at bottom and partly on one side.	.656 by .656	.633	.636	.637
	.328	.658	.656	.654
	.164	.676	.673	.672
	.098	.682	.683	.681
	.033	.708	.705	.695
Suppressed at bottom and partly on two sides.	.656 by .656	.678	.664	.663
		.680	.675	.672
		.687	.680	.673
		.693	.688	.683
		.708	.705	.698
Suppressed on bottom and two sides	.656 by .656	.690	.677	.672
Complete suppression	.656 by .656	......	.950	

TABLE. 26.—MISCELLANEOUS COEFFICIENTS OF DISCHARGE FOR VARIOUS SHARP-EDGED SUBMERGED ORIFICES. THE TWO ORIFICES EXPERIMENTED ON BY ELLIS WERE HORIZONTAL. ALL OTHER ORIFICES WERE VERTICAL

Dimensions of orifice in feet	Authority	Head in feet							
		0.3	0.5	1.0	2.0	4.0	6.0	10.0	18.0
Circle, d = .05......	H. Smith	....	.599	.597	.595	.595			
Circle, d = .10......	H. Smith	.600	.600	.600	.599	.598			
Square, .05 by .05..	H. Smith	....	.609	.607	.605	.604			
Square, .10 by .10..	H. Smith	.607	.605	.604	.603	.604			
Rectangle, l = 3.0, d = .05.	H. Smith	....	.621	....	....	.620	.620	.618	
Circle, d = 1.0......	Ellis	....	....	....	.608	.602	.603	.600	.601
Square, 1.0 by 1.0..	Ellis	....	....	....	.601	.601	.603	.605	.606
Square, 4.0 by 4.0..	Stewart	.614							

TABLE 27.—COEFFICIENTS OF DISCHARGE FOR SUBMERGED VERTICAL SQUARE ORIFICE WITH ROUNDED CORNERS. FROM EXPERIMENTS BY ELLIS.

Dimensions of orifice in feet	Head in feet								
	3	4	5	6	8	10	12	14	18
Square, 1.0 by 1.0.......	.952	.948	.946	.945	.944	.943	.943	.944	.944

TABLE 28.—COEFFICIENTS OF DISCHARGE FOR MODELS A, B, C, D, E AND F, FIGS. 24 AND 25, PAGE 45

Figure	Depth of opening in feet	Values of C for various depths of water above top of orifice										
		0.07	0.1	0.3	0.5	0.7	1.0	2.0	3.0	5.0	7.0	10.0
A	1.31	....	....	.597	.604	.610	.616	.618	.610	.608	.594	.592
	0.66	....	....	.632	.638	.640	.641	.640	.638	.637	.636	.634
	0.16	....	....	.691	.688	.684	.683	.678	.674	.672	.670	.668
	0.10	....	....	.711	.700	.695	.692	.688	.682	.677	.675	.672
B	1.31	....	....	.643	.650	.654	.656	.649	.636	.620	.615	.611
	0.66	....	....	.664	.670	.674	.675	.676	.674	.673	.671	.669
	0.16	....	....	.662	.681	.688	.693	.695	.694	.692	.691	.689
	0.10	....	....	.693	.700	.705	.708	.710	.705	.699	.695	.693
C	1.31	....	....	.648	.654	.658	.660	.652	.638	.622	.616	.612
	0.66	....	....	.667	.673	.676	.678	.679	.677	.674	.672	.670
	0.16	....	....	.664	.682	.690	.695	.697	.696	.693	.692	.690
	0.10	....	....	.695	.702	.707	.710	.712	.706	.699	.695	.693
D	0.656	.487	.495	.539	.562	.577	.588	.601	.601	.601	.601	.601
	0.164	.495	.550	.619	.630	.631	.630	.625	.624	.619	.612	.606
E	0.656	.487	.495	.530	.554	.573	.580	.595	.599	.602	.602	.601
	0.164	.495	.544	.600	.612	.618	.623	.627	.628	.627	.622	.617
F	0.656	.530	.535	.569	.584	.595	.600	.608	.610	.610	.609	.608
	0.164	.590	.600	.628	.640	.645	.649	.652	.651	.650	.650	.649

Table 29.—Coefficients of Discharge, C, for Submerged Gates from Chatterton's and Benton's Formulas
Formulas (16) and (17), page 46

Head in feet	Authority	Width of opening in feet					
		2	4	6	8	10	12
.02	Chatterton....	.83	.83	.83	.83	.83	.83
	Benton........	.73	.75	.76	.78	.79	.81
.05	Chatterton....	.83	.83	.83	.83	.83	.83
	Benton........	.73	.75	.76	.78	.79	.81
.10	Chatterton....	.82	.82	.82	.82	.82	.82
	Benton........	.73	.75	.76	.78	.79	.81
15	Chatterton....	.82	.82	.82	.82	.82	.82
	Benton........	.73	.75	.76	.78	.79	.81
.2	Chatterton....	.81	.81	.81	.81	.81	.81
	Benton........	.73	.75	.76	.78	.79	.81
.3	Chatterton....	.80	.80	.80	.80	.80	.80
	Benton........	.73	.75	.76	.78	.79	.81
.4	Chatterton....	.78	.78	.78	.78	.78	.78
	Benton........	.73	.75	.76	.78	.79	.81
.5	Chatterton....	.77	.77	.77	.77	.77	.77
	Benton........	.73	.75	.76	.78	.79	.81
.75	Chatterton....	.75	.75	.75	.75	.75	.75
	Benton........	.73	.75	.76	.78	.79	.81
1.0	Chatterton....	.73	.73	.73	.73	.73	.73
	Benton........	.73	.75	.76	.78	.79	.81
1.5	Chatterton....	.69	.69	.69	.69	.69	.69
	Benton........	.73	.75	.76	.78	.79	.81
2.0	Chatterton....	.67	.67	.67	.67	.67	.67
	Benton........	.73	.75	.76	.78	.79	.81
2.5	Chatterton....	.65	.65	.65	.65	.65	.65
	Benton........	.73	.75	.76	.78	.79	.81
3.0	Chatterton....	.64	.64	.64	.64	.64	.64
	Benton........	.73	.75	.76	.78	.79	.81
3.5	Chatterton....	.64	.64	.64	.64	.64	.64
	Benton........	.73	.75	.76	.78	.79	.81
4.0	Chatterton....	.63	.63	.63	.63	.63	.63
	Benton........	.73	.75	.76	.78	.79	.81
4.5	Chatterton....	.63	.63	.63	.63	.63	.63
	Benton........	.73	.75	.76	.78	.79	.81
5.0	Chatterton....	.62	.62	.62	.62	.62	.62
	Benton........	.73	.75	.76	.78	.79	.81

TABLE 30.—COEFFICIENTS OF DISCHARGE, C, FOR SUBMERGED TUBES. COMPILED FROM EXPERIMENTS BY STEWART, AND ROGERS AND SMITH. L = LENGTH OF TUBE. p = PERIMETER OF CROSS-SECTION OF TUBES

$\frac{L}{p}$	Condition of edges at entrance				
	All corners square	Contractions suppressed on bottom only	Contractions suppressed on bottom and one side	Contractions suppressed on bottom and two sides	Contractions suppressed on bottom, two sides and top
.02	.61	.63	.68	.77	.95
.04	.62	.64	.68	.77	.94
.06	.63	.65	.69	.76	.94
.08	.65	.66	.69	.74	.93
.10	.66	.67	.69	.73	.93
.12	.67	.68	.70	.72	.93
.14	.69	.69	.71	.72	.92
.16	.71	.70	.72	.72	.92
.18	.72	.71	.73	.72	.92
.20	.74	.73	.74	.73	.92
.22	.75	.74	.75	.75	.91
.24	.77	.75	.76	.78	.91
.26	.78	.76	.77	.81	.91
.28	.78	.76	.78	.82	.91
.30	.79	.77	.79	.83	.91
.35	.79	.78	.80	.84	.90
.40	.80	.79	.80	.84	.90
.60	.80	.80	.81	.84	.90
.80	.80	.80	.81	.85	.90
1.00	.80	.81	.82	.85	.90

CHAPTER IV

SHARP-CRESTED WEIRS

Any obstruction, of regular section, so placed across the channel of a stream that water flows over it, is called a weir. An orifice becomes a weir when its sides intersect the surface of the water, the overfalling water then coming into contact only with the two sides and bottom of the opening. The bottom of this opening is termed the *crest of the weir*. The overfalling sheet of water is commonly called the *nappe*.

A weir may be designed with sharp corners so that the water in discharging touches only the inner edges of the sides or crest. In such cases there is a contraction of the nappe similar to the contraction of a jet issuing from an orifice. There is also a contraction or depression of the water surface beginning at a distance upstream from the weir equal to about twice the depth of water passing over the weir.

When the weir is so designed that the nappe touches only the upstream edge of the crest it is called a *sharp-crested or thin-edged weir*. Similarly, if the nappe touches only the upstream edge of the sides the weir is said to have *end contractions*. When there is no contraction at the sides of the nappe the weir is said to have *suppressed contractions*, and the weir is called a *suppressed weir*. The most common example of a suppressed weir is where the channel is of rectangular cross-section and the length of the weir equals the width of the channel.

The velocity of approach is usually understood to be the mean velocity of the water in the channel, just above the weir. *The velocity of retreat* is the mean velocity of the water in the channel as it leaves the weir.

Sharp-crested weirs are used only for the purpose of measuring water. With weirs not sharp-crested the measurement of water is usually though not necessarily a secondary consideration. Overflow dams and spillways for reservoirs are examples of weirs not sharp-crested.

Thin-edged weirs as usually constructed have a rectangular,

trapezoidal, or triangular shape. Rectangular and trapezoidal weirs ordinarily have level crests. Triangular weirs should be so set that their sides make equal angles with the vertical.

When the elevation of the water surface below a weir is less than the elevation of its crest it is called *a weir with free overfall*. When the crest of the weir is below the elevation of the lower water surface the weir is said to be *submerged* or *drowned*.

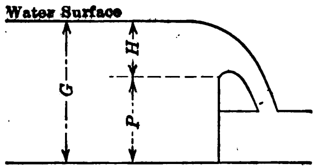


Fig. 26.—Weir with free overfall.

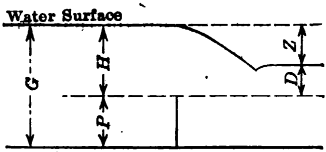


Fig. 27.—Submerged weir.

Referring to Figs. 26 and 27, the following nomenclature will be used:

For all weirs:

H = Measured head or difference in elevation between the crest of weir and the water surface above the weir.

A = Area of section of channel of approach.

W = Width of the channel of approach.

P = Height of weir above the bottom of the channel of approach.

Q = Discharge over weir in second-feet.

V = Mean velocity of approach $= \frac{Q}{A}$.

g = Acceleration due to gravity.

h = Velocity head $= \frac{V^2}{2g}$.

G = Depth of water above the weir $= P + H$.

d = Area of section of channel of approach divided by the length of the weir.

$C, C_1, C_2, \alpha, \beta$, etc. = Empirical coefficients.

For suppressed weirs:

L = Measured length of weir.

$d = \frac{A}{L} = G$ = Depth of water above the weir.

For weirs with end contractions:

L' = Measured length of weir.

L = Length of weir corrected for end contractions.

N = Number of end contractions.

$d = \frac{A}{L}$ for any channel of approach and $\frac{WG}{L}$ for a rectangular channel of approach.

For submerged weirs:

D = Depth of submergence.

$Z = H - D$ = The difference in elevation of water surface above and below weir.

d_1 = Area of section of channel below the weir divided by the length of weir.

Rectangular Weirs with Free Overfall

Fundamental Considerations.—The theoretical discharge over a rectangular weir with free overfall (page 37) is given by the formula

$$Q_t = \tfrac{2}{3} \sqrt{2g}\, LH^{3/2} \tag{1}$$

An empirical factor corresponding to the coefficient of discharge for an orifice is usually applied to the theoretical formula. This coefficient may be considered as the product of the coefficients of velocity and contraction. Including this coefficient and combining it with $\sqrt{2g}$, which is assumed to be a constant, the formula may be written

$$Q = CLH^{3/2} \tag{2}$$

If the above equation represented accurately the law of the flow of water over weirs, the value of C could be readily determined experimentally. It is known, however, that C is not exactly a constant. The problem is also complicated by the fact that the discharge is affected by the velocity of approach, the effect of which is to increase the discharge.

Modern Weir Formulas.—Many formulas have been suggested for determining the discharge over rectangular, sharp-crested weirs with free overfall. For the most part such formulas have been based upon the experiments of Francis,[1] Fteley and Stearns,[2] and Bazin.[3]

[1] J. B. Francis: Lowell Hydraulic Experiments. Also *Trans.* Amer. Soc. Civ. Eng., vol. 13, p. 303.

[2] *Trans.* Amer. Soc. Civ. Eng., vol. 12.

[3] *Annales des Ponts et Chaussees*, October, 1888. Translation by Marichal and Trautwine: *Proc.* Eng. Club, Phila., January, 1890. Also *Annales des Ponts et Chaussees* for 1894, 1er Trimestre.

The following are the more commonly used weir formulas, written to include the velocity of approach correction:

1. The Francis formula for sharp-crested weirs, with and without end contractions

$$Q = 3.33L\left[(H + h)^{3/2} - h^{3/2}\right] \tag{3}$$

When there are end contractions L is to be corrected by the formula

$$L = L' - 0.1NH \tag{4}$$

2. The Fteley and Stearns formula for sharp-crested weirs with and without end contractions

$$Q = 3.31L\,(H + \alpha h)^{3/2} + 0.007\,L \tag{5}$$

When there are end contractions L is to be corrected by the formula

$$L = L' - 0.1NH \tag{4}$$

$\alpha = 1.50$ for suppressed weirs and 2.05 for weirs with end contractions.

3. The Bazin formula for suppressed weirs

$$Q = \left(0.405 + \frac{0.00984}{H}\right)\left(1 + 0.55\,\frac{H^2}{d^2}\right)LH\sqrt{2gH} \tag{6}$$

4. Lyman's diagram[1] gives discharges for suppressed weirs, which includes velocity of approach correction. The reader is referred to the original publication for this diagram.

The author also submits his formula for sharp-crested weirs, either with or without end contractions

$$Q = 3.34LH^{1.47}\left(1 + 0.56\frac{H^2}{d^2}\right) \tag{7}$$

When there are end contractions L is to be corrected by the formula

$$L = L' - 0.1NH \tag{4}$$

Each of the above formulas will be discussed in turn.

The Francis Formula.—Up to the present time the Francis formula has been more generally used than any other weir formula. Francis based his formula upon his experiments[2] at Lowell, Mass., in 1852. The following is the approximate range of conditions under which the experiments were performed:

Head	0.6 to 1.6 feet
Length of weir	8.0 and 10.0 feet
Height of weir	2.0 and 5.0 feet
Width of channel	10.0 and 14.0 feet
Velocity of approach	0.2 to 1.0

[1] Plate XXI, *Trans.* Am. Soc. Civ. Eng., vol. 77.

[2] J. B. Francis; Lowell Hydraulic Experiments, pp. 103–135.

With these experiments as a basis Francis investigated the general formula

$$Q = C_1 L H^n \tag{8}$$

He obtained 1.47 for a value of n but used 1.5, finally adopting as the formula which represented the mean of his observations, not including the velocity of approach correction

$$Q = 3.33\, LH^{1.5} \tag{9}$$

The experimental values of C ranged from 3.31 to 3.36, so that the mean value selected deviated by nearly 1 per cent. from the results of his own experiments. The general Francis formula, as written to include velocity of approach correction, is given on page 66, formula (3).

The later experiments of Fteley and Stearns, and Bazin show that the Francis formula may give results in error by 5 or 10 per cent. The formula is especially unreliable for low weirs having a high velocity of approach and for low heads under all conditions.

One reason for the extensive use of the Francis formula is doubtless because of its supposed simplicity. In reality, however, with the Francis method of correcting for velocity of approach it is as complicated as any of the other weirs formulas. Without the velocity of approach correction, the Francis formula can be easily remembered and may be used for rough computations. Where accuracy is essential the formula should be discarded, unless the conditions of measurement correspond approximately to those of the Francis experiments.

The Francis correction for end contractions

$$L = L' - 0.1NH \tag{4}$$

still appears to be as satisfactory as any that has yet been suggested. Additional experimental data regarding this matter, however, are badly needed. Many engineers prefer the use of weirs with suppressed contraction because of the uncertainty which exists regarding the proper correction for end contractions.

Table 39, page 117, gives discharges in cubic feet per second per foot of length over sharp crested weirs, without velocity of approach correction, by the Francis formula, for heads from 0 to 7 feet.

The Fteley and Stearns Formula.—Fteley and Stearns,[1] 1877–79, experimented with two sharp-crested suppressed weirs, 5 and 19 feet long and 3.17 and 6.55 feet high respectively. Heads on the former were observed up to approximately 0.8 feet, and on the latter to 1.6 feet. The respective velocities of approach reached maximums of about 0.6 and 0.8 feet per second. They also experimented on a weir with end contractions 3.56 feet high with lengths of from 2.3 to 4.0 feet. Heads on this weir were read up to nearly 1.0 feet, the maximum velocity of approach being 0.54 feet per second.

The Fteley and Stearns formula (formula (5), page 66) was derived from the results of the above experiments combined with those of Francis. The term $0.007L$ in the formula was added to make it agree with their low-head experiments. The later experiments of Bazin (see Appendix A) show discharges approximately 3 per cent. greater for the low heads than were obtained by Fteley and Stearns. Additional experiments are needed to clear up the apparent inconsistencies in the results of these two investigators.

The Bazin Formula.—By far the most complete weir experiments that have yet been performed were those of Bazin[2] in 1886. Bazin experimented on suppressed weirs in a concrete channel, with vertical sides, 2 meters wide. The head was measured 16.4 feet upstream from the weir by means of a hook gage. These experiments were especially valuable in that weirs of several heights were used and the effect of velocity of approach on discharge could be studied. The results of 381 experiments in all are given. The lowest head observed by Bazin was about 0.3 feet. Below this head there was a tendency for the nappe to adhere to the downstream face of the weir. The following is a summary of Bazin's experiments:

Number of experiments	Length of weir in feet	Height of weir in feet	Maximum head in feet
67	6.56	3.72	1.017
38	3.28	3.72	1.340
48	1.64	3.30	1.780
58	6.56	2.47	1.433
58	6.56	1.64	1.407
68	6.56	1.16	1.338
44	6.56	0.79	1.338

[1] *Trans.* Amer. Soc. Civ. Eng., vol. 12, pp. 1–118.

[2] *Annales des Ponts et Chaussees*, October, 1888.

From these experiments Bazin derived his formula for suppressed weirs. He began his study with the fundamental expression

$$Q = C_1 LH\sqrt{2gH} \tag{10}$$

which corrected for velocity of approach becomes

$$Q = C_1 L\sqrt{2g}\left(H + \alpha\frac{V^2}{2g}\right)^{3/2} \tag{11}$$

Also

$$V = \frac{Q}{A} = \frac{Q}{dL} \tag{12}$$

Substituting for Q in equation (12) its approximate value in equation (10)

$$V = \frac{C_1\, LH\sqrt{2gH}}{dL} = \frac{C_1\sqrt{2g}H^{3/2}}{d}$$

Substituting this value of V in equation (11) there results the expression

$$Q = C_1\, LH\sqrt{2gH}\left(1 + \alpha C_1^2\frac{H^2}{d^2}\right)^{3/2}$$

Expanding by the binomial theorem and neglecting all terms except the first two since they will always be very small quantities

$$Q = C_1\, LH\sqrt{2gH}\left(1 + \frac{3}{2}\alpha C_1^2\frac{H^2}{d^2}\right) \tag{13}$$

Or considering the expression $3\alpha C_1^2$ as a coefficient the value of which is to be determined, equation (13) may be written.

$$Q = C_1 LH\sqrt{2gH}\left(1 + C_2\frac{H^2}{d^2}\right) \tag{14}$$

If the above formula, with constant values of the two coefficients, expressed accurately the law of flow over weirs the determination of the value of these coefficients would be a simple matter. Bazin found, however, that constant values of each coefficient could not be so chosen as to make results determined by the formula agree with his experimental discharges. After a careful analysis of his experiments and those of Fteley and Stearns he chose the following values, reduced from metric to English units:

$$C_1 = 0.405 + \frac{0.00984}{H} \tag{15}$$

$$C_2 = 0.55 \tag{16}$$

making the completed equation (equation (6), page 66), as already given.

Another method of correcting for velocity of approach is as follows. The fundamental weir formula without velocity of approach may be written

$$Q = \frac{2}{3} CLH \sqrt{2gH} \tag{17}$$

This formula may be taken to consist of two parts, CLH and $\frac{2}{3}\sqrt{2gH}$. CLH may be considered the area of the opening corrected for crest and surface contraction and $\frac{2}{3}\sqrt{2gH}$ the theoretical mean velocity. It appears more reasonable to the author that H should be corrected for velocity of approach only insofar as it is the head producing the velocity. H in the first part of the equation enters into it solely as a factor in the area of the opening, which is not changed by velocity of approach. Under this assumption, equation (17), when corrected for velocity of approach, may be written

$$Q = C_1 L \sqrt{2g}\, H \left(H + \beta \frac{V^2}{2g}\right)^{\frac{1}{2}} \tag{18}$$

and since

$$V = Q/dL \tag{12}$$

this value of V may be substituted in equation (18), and solving for Q there results

$$Q = \frac{C_1 L \sqrt{2g} H^{\frac{3}{2}}}{\sqrt{1 - C_1^2 \beta \frac{H^2}{d^2}}} \tag{19}$$

Expanding the denominator of this expression by the binomial theorem and neglecting all terms of the fourth power and above, which will always be very small quantities,

$$Q = C_1 L \sqrt{2g} H^{\frac{3}{2}} \left(1 + \frac{C_1^2 \beta}{2} \cdot \frac{H^2}{d^2}\right) \tag{20}$$

or the equivalent expression

$$Q = C_1 L \sqrt{2g}\, H^{\frac{3}{2}} \left(1 + C_2 \frac{H^2}{d^2}\right) \tag{21}$$

which is the form of the formula for discharge over a weir based upon the theoretical formula and the above assumption for velocity of approach.

It will be observed that equations (14) and (21), though based upon different assumptions, are of the same general form. The only difference is in the factors that enter into the value of C_2 which in either case is empirical and must be determined by experiment. By equating the values of C_2 in the two equations it will be seen that $\beta = 3\alpha$.

Lyman's Diagram.—The results of a very thorough investigation, of all of the accepted weir experiments available at the time, was published by Lyman[1] in 1913. In this connection a diagram was prepared which gives discharges over sharp-crested suppressed weirs. This diagram conforms very closely to the experiments of Francis, Fteley and Stearns, and Bazin, as well as additional experiments by himself. The diagram is convenient for use but is limited to heads below 1.6 feet.

The Author's Formula.—The author has investigated the flow of water over sharp-crested weirs, using as a basis the work and experiments of Francis, Fteley and Stearns, and Bazin, to determine the extent to which existing weir formulas are consistent with these experiments. In connection with his investigation the author derived the formula which is discussed below. Comparative results by these various formulas are shown in Appendix A.

Starting with the expression

$$Q = C_1 \sqrt{2g} L H^{3/2} \left(1 + C_2 \frac{H^2}{d^2}\right) \qquad (14 \text{ or } 21)$$

It has already been stated that constant values of C_1 and C_2 cannot be so chosen as to make this formula fit the results of existing experimental data. Some modification in form is therefore necessary. Bazin's method of accomplishing this is given on page 69.

After many trials and a careful comparison with the experimental results of Bazin, Fteley and Stearns, and Francis, the following values of C_1 and C_2 in the above equation were finally adopted:

$$C_1 = \frac{0.4165}{H^{0.03}}$$

$$C_2 = 0.56$$

[1] RICHARD R. LYMAN: Measurement of the Flow of Streams by Approved Forms of Weirs, with New Formulas and Diagrams. *Trans.* Amer. Soc. Civ. Eng., vol. 77, pp. 1189–1337.

The above value of C_1 indicates that the coefficient of contraction for sharp crested weirs varies with $H^{-0.03}$. It will be observed that the author's value of C_2 is very nearly the same as that chosen by Bazin.

Using the nomenclature given on page 64 and substituting the above values of C_1 and C_2 in formula (14 or 21), with $g = 32.16$, the author's general formula for discharge over sharp crested weirs, both with and without end contractions, becomes:

$$Q = 3.34LH^{1.47}\left(1 + 0.56\,\frac{H^2}{d^2}\right) \qquad (7)$$

For weirs with end contractions, and especially if the channel of approach is irregular, the formula may be more convenient in the form

$$Q = 3.34LH^{1.47}\left[1 + 0.56\left(\frac{LH}{A}\right)^2\right] \qquad (7a)$$

When there are end contractions L is to be corrected by the formula

$$L = L' - 0.1NH \qquad (4)$$

The following is a summary of conclusions resulting from the author's study of sharp-crested weirs, all of which are believed to be substantiated by the results shown in Appendix A.

1. The author's formula (formula (7) or (7a)) agrees more closely with the Bazin experiments on suppressed weirs than any of the commonly used weir formulas which have been discussed above (see Appendix A, Tables 102 and 103 and Fig. 89).

2. The author's formula gives results about 2 per cent. greater than those obtained by the Fteley and Stearns experiments. There is a very apparent inconsistency between these experiments and those of Bazin, especially for the lower heads, and it is impossible to obtain a formula which will agree with both sets of experiments. The author has designed his formula to conform to the results obtained by Bazin (see Appendix A, Tables 104, 105, 106 and 107 and Figs. 90 and 91).

3. The author's formula gives results agreeing with the Francis experiments on weirs with end contractions within a maximum discrepancy of about 2 per cent. In general this discrepancy is but slightly greater than that of the Francis formula applied to the same experiments (see Appendix A, Tables 106 and 107, and Fig. 91).

4. As a general formula applied to all of the experiments the

author's formula shows a much closer agreement than either the Bazin, Fteley and Stearns or Francis formulas.

5. A formula which does not require a separate correction for velocity of approach, if not too complicated, may be more readily used than a formula requiring such a correction. The author's formula like the Bazin formula does not require a separate correction for velocity of approach and it possesses advantages over the Bazin formula from the standpoints of accuracy, simplicity and range of application.

A set of experiments on a weir, exactly duplicating the dimensions of Bazin's standard weir (2 meters wide and 3.72 feet high) with heads ranging from 0.4 to 4.0 feet have recently (May, 1917) been completed by Nagler.[1] Heads were measured by means of hook gages and discharges were determined by chemical gaging (page 249). Great care was taken in conducting these experiments and there is every indication of a high degree of accuracy in the results. A brief summary of conclusions based upon the results of Nagler's experiments is as follows.

1. Nagler's results agree with the results of Bazin's experiments (between heads of 0.4 and 1.4 feet, the range of heads common to each set of experiments) within a maximum discrepancy of 1 per cent. and an average discrepancy of 0.4 per cent.

2. Nagler's experiments show practically the same discrepancy with the Fteley and Stearns experiments as exists between the Bazin experiments and Fteley and Stearns experiments.

3. The author's formula agrees with the Bazin experiments much closer than with Nagler's experiments. The agreement with Nagler's experiments appears close enough to justify the conclusion that the author's formula is reliable, within a probable error of 1 per cent., for heads from the lowest up to 4 feet.

The term $3.34LH^{1.47}$ in the author's formula (formula (7) or (7*a*) page 72) gives discharges without velocity of approach correction. The expression within the parentheses is the factor correcting for velocity of approach. When the area of the channel of approach is large in comparison with the area of the weir opening, or for rough computations, the velocity of approach correction may be neglected, the formula becoming

$$Q = 3.34LH^{1.47} \tag{22}$$

[1] F. A. Nagler: Verification of the Bazin Weir Formula by Hydro-Chemical Gagings. *Proc.* Amer. Soc. Civ. Eng., Jan., 1918.

Table 33, page 98, gives values of $3.34\ H^{1.47}$ for heads from 0 to 2 feet with an interval of 0.001 feet, and for heads from 2 to 7 feet with an interval of 0.01 feet. Table 34, page 103, gives values of $1 + .56\ \frac{H^2}{d^2}$ for intervals of $\frac{H}{d}\left(\text{or } \frac{LH}{A}\right)$ differing by 0.001. To determine the discharge, with velocity of approach correction, per linear foot of weir, H and $\frac{H}{d}\left(\text{or } \frac{LH}{A}\right)$ being known, multiply the discharge given in Table 33 by the corrective factor given in Table 34. The total discharge for a weir of any length, will be this product multiplied by the length of weir, corrected for end contractions if necessary by the formula

$$L = L' - 0.1NH \tag{4}$$

Table 32, page 93, gives values of $H^{1.47}$ with intervals of 0.001 from 0 to 2 feet and with intervals of 0.01 from 2 to 7 feet.

Table 35, page 104, gives discharges by the author's formula over sharp-crested suppressed weirs per foot of length for different heights of weir under heads of from 0.2 to 1.64 feet.

Precautions for Accurate Use of Sharp-crested Weirs

In order to obtain the most accurate results from weir formulas, they should be limited in their use as far as practicable to the conditions of the experiments on which they are based. The following are some of the precautions to be observed and conditions to be fulfilled.

1. The head should be measured far enough upstream from the weir to be above the effect of surface contraction. Francis and Fteley and Stearns measured heads 6 feet, and Bazin 16.4 feet upstream from the weir. Experiments seem to indicate that no effect of surface contraction can be detected at a distance of $2.5H$ back of the weir and from this point up to a distance of 16.4 feet, H appears to be constant excepting insofar as it is affected by the surface slope necessary to produce velocity in the channel of approach. As the author's weir formula is based in a large measure on Bazin's experiments, it appears that H should preferably be measured at a distance of approximately 16 feet upstream from the weir when using this formula.

2. For the best results H should be measured by means of a hook gage in a well or stilling-box connected by a pipe to the

channel. This pipe should enter the channel flush with the surface in order that the elevation of the water surface in the well may not be effected by the velocity of the water. Where long weirs are used, simultaneous readings are sometimes made in separate stilling-boxes connected to each side of the channel and perhaps one or more points on the bottom in order to obtain a more accurate mean value of H. The head should preferably be determined from the mean of at least 20 observations taken at equal intervals of about 20 or 30 seconds in order to eliminate the effects of waves in the channel of approach which cause a fluctuation of the elevation of the water surface in the well.

3. The crest of the weir should be so constructed as to insure perfect contraction. This requires that the upstream edge shall be sharp and smooth and that the crest shall be thin enough to prevent any tendency of the water to adhere to its top surface. Special care is necessary when H is less than 0.3 feet to prevent the nappe from adhering to the top or downstream faces of the weir. When H is less than 0.2 feet, it becomes difficult to prevent such adherence and the formula for sharp-crested weirs becomes unreliable. For high heads the thickness of the weir crest is not of so great importance as long as the upstream edge is sharp. The nappe, when thoroughly aerated, will spring clear of the edge if the width of crest is not more than $\frac{1}{2}H$. The thin weir is preferable for accurate work, however, under all conditions. A metal crest free from rust, with a sharp right-angled corner on the upstream edge, a crest width of $\frac{1}{8}$ inch and beveled to the thickness of the metal on the lower face, should give satisfactory results. The upstream face of the weir should be vertical and the crest should be level.

4. The nappe should be perfectly aerated. This usually requires the construction of air passages leading to the space beneath the nappe of suppressed weirs. For weirs with end contractions, the length of the weir being less than the width of the channel, no special provision for aeration is necessary. Francis states that in order to assure perfect aeration of the nappe, the elevation of the water surface on the downstream side of the weir should be at least $\frac{1}{2}H$ below the crest of the weir.

5. To obtain the best results from weir formulas their use should be limited as far as practicable to the range of experimental data on which they are based. In general the author's

formula may be used with more assurance for weirs from 1 to 4 feet high and where the heads are from 0.2 to 1.5 feet, though Nagler's experiments (page 73) indicate that the formula is equally accurate up to heads of 4 feet for a weir 3.72 feet high. On account of the wide range of the experiments on which the author's formula is based it seems reasonable to believe that it will probably give satisfactory results for higher weirs and greater heads than have yet been used in any experiments.

Submerged Weirs

When the elevation of water surface in the channel below a weir is above the crest, the weir is said to be submerged or drowned. The problems involved in determining discharges over submerged weirs are complicated and have not been completely investigated. The nomenclature used in the following discussion is given on pages 64 and 65 (see Fig. 27).

A theoretical formula for discharge over submerged weirs may be obtained by dividing the overflow into two parts, the portion above the level of the lower water surface being considered as a weir and the remainder being treated as a submerged orifice. The theoretical combined discharge is then

$$Q = \sqrt{2g}L\,[\tfrac{2}{3}(H - D)^{3/2} + D\,(H - D)^{1/2}] \tag{23}$$

or since $H - D = Z$

$$Q = \tfrac{2}{3}\sqrt{2g}LZ^{3/2} + \sqrt{2g}\,L\,\sqrt{Z}\,D \tag{24}$$

or

$$Q = L\sqrt{Z}\,(C_1\,Z + C_2\,D) \tag{25}$$

C_1 and C_2 being empirical coefficients whose values are to be determined. This basic formula was used by Francis, and Fteley and Stearns in obtaining their submerged-weir formulas.

Experiments on submerged weirs have been performed by Francis, Fteley and Stearns, and Bazin, which form the basis of several submerged-weir formulas.

The Francis[1] experiments of 1848 were performed on a weir 6.5 feet high. The quantity of water, which was kept practically constant, was measured on a weir with free overfall. The measured head on the weir varied from 0.85 to 0.97 feet and the depth of submergence ranged from 0.02 to 0.49 feet.

In 1883 Francis[2] experimented with a weir 5.8 feet high, the discharge being measured by a weir with free overfall. In

[1] J. B. Francis: Lowell Hydraulic Experiments, p. 102.

[2] *Trans.* Amer. Soc. Civ. Eng., vol. 13, p. 303.

these experiments the head varied from approximately 1.1 to 2.3 feet and the depth of submergence from 0.2 to 1.1 feet.

The Fteley and Stearns[1] experiments, 1882, were performed on a weir 3.17 feet high, the head ranging from 0.40 to 0.81 feet and the depth of submergence from 0.1 to 0.8 feet. The discharges were determined from a weir with free overfall.

In each of the above sets of experiments the cross-section of the channel below the weir had a greater area than the cross-section of the channel above the weir.

Bazin[2] experimented on submerged weirs 0.24 meters, 0.35 meters, 0.50 meters, and 0.75 meters high by comparing the discharges over these weirs with discharges over his standard weir 3.72 feet high. These weirs were constructed in a rectangular channel 2 meters wide, the length of the weirs being the same as the width of the channel. The following table gives the approximate range of these experiments expressed in English units:

P in feet	Minimum		Maximum	
	H in feet	D in feet	H in feet	D in feet
0.79	0.34	0.13	1.49	1.31
1.14	0.19	0.09	1.47	1.30
1.64	0.21	0.06	1.43	1.18
2.47	0.33	0.10	1.36	0.98

Between the limits expressed in this table the experiments covered intermediate values of H and D. In all 326 experiments are recorded. Heads were measured 5 meters upstream and 11 meters downstream from the weir.

Francis Submerged-weir Formula.—Starting with the fundamental formula (formula (25)), from his experiments in 1883 Francis derived the following formula for discharge over submerged weirs:

$$Q = 3.33\, L\sqrt{Z}\, (H + 0.381D). \tag{26}$$

Fteley and Stearns Submerged-weir Formula.—From their own experiments in connection with the Francis experiments of 1848, Fteley and Stearns adopted the formula

$$Q = CL\sqrt{Z}\left(H + \frac{D}{2}\right) \tag{27}$$

[1] *Trans.* Amer. Soc. Civ. Eng., vol. 12, p. 104.

[2] *Annales des Ponts et Chaussees* for 1894, 1er Trimestre, p. 249.

and prepared the following table of values of C, corresponding to different values of D/H, to accompany the formula:

Coefficient C, Fteley and Stearns's Submerged-weir Formula

$\frac{D}{H}$	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
0.0	.....	3.330	3.331	3.335	3.343	3.360	3.368	3.371	3.372	3.370
.1	3.365	3.359	3.352	3.343	3.335	3.327	3.318	3.310	3.302	3.294
.2	3.286	3.278	3.271	3.264	3.256	3.249	3.241	3.234	3.227	3.220
.3	3.214	3.207	3.201	3.194	3.188	3.182	3.176	3.170	3.165	3.159
.4	3.155	3.150	3.145	3.140	3.135	3.131	3.127	3.123	3.119	3.116
.5	3.113	3.110	3.107	3.104	3.102	3.100	3.098	3.096	3.095	3.093
.6	3.092	3.091	3.090	3.090	3.089	3.089	3.089	3.090	3.090	3.091
.7	3.092	3.093	3.095	3.097	3.099	3.102	3.105	3.109	3.113	3.117
.8	3.122	3.127	3.131	3.137	3.143	3.150	3.156	3.164	3.172	3.181
.9	3.190	3.200	3.209	3.221	3.233	3.247	3.262	3.280	3.300	3.325

Herschel Submerged-weir Formula.—Basing his investigation[1] on the experiments of Francis in 1848 and 1883, and the Fteley and Stearns experiments, Herschel adopted the formula

$$Q = 3.33\,L(NH)^{3/2} \tag{28}$$

and prepared the following table of values of N corresponding to different values of D/H to accompany the formula. The velocity of approach correction is the same as the Francis correction for weirs with free overfall.

Coefficient N, Herschel's Submerged-weir Formula

$\frac{D}{H}$	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
0.0	1.000	1.004	1.006	1.006	1.007	1.007	1.007	1.006	1.006	1.005
.1	1.005	1.003	1.002	1.000	.998	.996	.994	.992	.989	.987
.2	.985	.982	.980	.977	.975	.972	.970	.967	.964	.961
.3	.959	.956	.953	.950	.947	.944	.941	.938	.935	.932
.4	.929	.926	.922	.919	.915	.912	.908	.904	.900	.896
.5	.892	.888	.884	.880	.875	.871	.866	.861	.856	.851
.6	.846	.841	.836	.830	.824	.818	.813	.806	.800	.794
.7	.787	.780	.773	.766	.758	.750	.742	.732	.723	.714
.8	.703	.692	.681	.669	.656	.644	.631	.618	.604	.590
.9	.574	.557	.539	.520	.498	.471	.441	.402	.352	.275

[1] *Trans.* Amer. Soc. Civ. Eng., vol. 14, p. 189.

Bazin Submerged-weir Formula.—The method adopted by Bazin in deducing a formula from his experiments was to obtain corrective factors to be applied to his formula for weirs with free overfall. Calling the ratio of the discharge of the submerged weir to the discharge of the weir with free overfall $\frac{m}{m_1}$ and using the nomenclature given on pages 64 and 65 he deduced the following formulas:

$$\frac{m}{m_1} = 1.06 + \frac{1}{4}\frac{D}{P} - \left[0.008 + \frac{1}{3}\frac{D}{P} + \frac{1}{3}\frac{D^2}{P^2}\right]\frac{P}{H} \tag{29}$$

$$\frac{m}{m_1} = \left(1.08 + 0.18\frac{D}{P}\right)\sqrt[3]{\frac{Z}{H}} \tag{30}$$

In general, formula (29) should be used for values of $\frac{m}{m_1}$ greater than 0.9 and formula (30) should be used for values less than 0.9. Bazin plotted the results of his experiments using $\frac{m}{m_1}$ and $\frac{P}{H}$ for coördinates arranged to give curves for similar values of $\frac{D}{P}$. Equation (29) and (30) are plotted on a diagram and the resulting curves come remarkably close to the mean of the experimental values. The exact limits of application of formulas (29) and (30) may be seen from this diagram.[1]

In a later publication[2] Bazin derived the following approximate general formula, applicable to all submerged weirs:

$$\frac{m}{m_1} = \left(1.05 + 0.21\frac{D}{P}\right)\sqrt[3]{\frac{Z}{H}} \tag{31}$$

and combining this formula with formula (6), page 66, there results the complete formula for discharge over submerged weirs

$$Q = \left(1.05 + 0.21\frac{D}{P}\right)\sqrt[3]{\frac{Z}{H}}\left(0.405 + \frac{0.00984}{H}\right)\left(1 + 0.55\frac{H^2}{d^2}\right) LH\sqrt{2gH} \tag{32}$$

The Author's Submerged-weir Formula.—Starting with the fundamental formula (page 76).

$$Q = L\sqrt{Z}\,(C_1Z + C_2D) \tag{25}$$

[1] Plate 8, *Annales des Ponts et Chaussees* for 1894, 1er Trimestre.

[2] *Annales des Ponts et Chaussees* for 1898, 1er Trimestre, p. 235.

in a manner similar to that employed for weirs with free overfall the correction for velocity of approach may be made to the head causing movement of the water, that is to the Z outside of the parenthesis, the Z within the parenthesis and D being considered purely as factors entering into the area of the opening. The formula corrected for velocity of approach, using the nomenclature given on pages 64 and 65 then becomes:

$$Q = L\left(Z + \beta\frac{V^2}{2g}\right)^{1/2} \cdot (C_1Z + C_2D) \tag{33}$$

or since $V = \dfrac{Q}{dL}$

$$Q = L\left(Z + \frac{\beta}{2g}\cdot\frac{Q^2}{d^2L^2}\right)^{1/2} \cdot (C_1Z + C_2D) \tag{34}$$

In a manner identical with that already explained for weirs with free overfall (page 70), by mathematical transformation, formula (34) may be reduced to the form

$$Q = L\sqrt{Z}\,(C_1Z + C_2D)\left[1 + C\,\frac{(C_1Z + C_2D)^2}{d^2}\right] \tag{35}$$

Equation (35) may be considered the theoretical form of formula for discharge over a submerged weir with velocity of approach correction. If this formula correctly expressed the law of flow over submerged weirs, values of the coefficients which it contains could be chosen to fit the available experimental data within the range of probable experimental error. This the author has been unable to do, but by using this formula as a base and modifying it as it appeared necessary he derived an empirical formula which gives results fairly concordant with all of the experiments investigated.

Francis does not give the distance below the weir at which the heads of submergence, for his experiments of 1848, were measured, but states that they were measured a "short distance" below the weir. In his experiments of 1883 he chose a distance of 18 feet below the weir for measuring heads. Fteley and Stearns measured heads of submergence 6 feet below the weir and Bazin made his measurements 36 feet below the weir.

There is always a tendency for a standing wave to form below a submerged weir. The result of this is to cause a depression of the water surface just below the place where the overfalling sheet joins the water of the lower channel. Below this depres-

sion there is a piling up of water and turbulence continues for some distance farther downstream.

It thus appears that considerable uncertainty must result when the head of submergence is measured where such turbulence exists. The author believes that in order that a formula of the form of equation (35) may be applicable, the head of submergence should be measured in the trough of the standing wave, that is where the lowest water surface occurs just below the overfalling sheet. The difference between the head of water passing over the weir and the depth of submergence measured in the trough of the standing wave is the true head causing discharge over the weir. There is not, in general, any effect of submergence until the trough of the wave reaches an elevation higher than the crest of the weir.

It is not ordinarily practicable, however, to measure the head of submergence in the trough of the standing wave because of the difficulty of determining the proper point of measurement and the tendency of the standing wave to shift its position with changing values of H and D. Moreover, in practical problems it is more frequently the elevation of the water surface in the channel below the weir after the normal conditions of flow have been established that is of greatest importance. A submerged-weir formula conforming to these conditions of measurement is therefore desirable.

As the author's formula is empirical no derivation can be given, but a brief discussion of the line of reasoning and steps taken in obtaining it is here given.

Starting with equation (35), page 80, and using the nomenclature given on pages 64 and 65,

$$Q = L\sqrt{Z}\,(C_1Z + C_2D)\left[1 + C\,\frac{(C_1Z + C_2D)^2}{d^2}\right] \qquad (35)$$

The equation, for trial, was modified and put in the form

$$Q = LZ^{0.47}\,(C_1Z + C_2D)\left(1 + C\,\frac{H^2}{d^2}\right) \qquad (36)$$

and then assuming that the form might be similar to that for weirs with free overfall it was written

$$Q = 3.34LZ^{0.47}\,(Z + C_3D)\left(1 + 0.56\,\frac{H^2}{d^2}\right) \qquad (37)$$

This equation resembles in form equation (35) and makes no allowance for the standing-wave conditions at the lower side

of the weir. When the head of submergence is measured in the channel below all turbulence caused by the overfalling sheet, this head will be greater than when it is measured in the trough of the standing wave. A factor may therefore be added to Z to make it equal the value of Z in the trough of the standing wave. After repeated trials, from Bazin's experiments, the writer found that the quantity by which Z should be increased appeared to vary directly as $\sqrt{ZHD}$ and inversely as $\sqrt{d_1}$ and modifying equation (37) accordingly

$$Q = 3.34L\left(Z + C_4\sqrt{\frac{ZHD}{d_1}}\right)^{0.47}(Z + C_3D)\left(1 + 0.56\frac{H^2}{d^2}\right) \tag{38}$$

which may be written

$$Q = 3.34LZ^{1.47}\left(1 + C_4\sqrt{\frac{HD}{d_1Z}}\right)^{0.47}\left(1 + C_3\frac{D}{Z}\right)\left(1 + 0.56\frac{H^2}{d^2}\right) \tag{39}$$

The factor within the first parenthesis, in the above equation, will not ordinarily exceed unity by more than 20 per cent. and it may therefore be put in a nearly equivalent form by writing the exponent 0.5 instead of 0.47, expanding by the binomial theorem and neglecting all terms except the first two. The equation may then be written

$$Q = 3.34LZ^{1.47}\left(1 + C_5\sqrt{\frac{HD}{d_1Z}}\right)\left(1 + C_3\frac{D}{Z}\right)\left(1 + 0.56\frac{H^2}{d^2}\right) \tag{40}$$

Values of the above coefficients were derived from the experimental data, and with these values substituted the author's formula for flow over submerged weirs, using the nomenclature given on pages 64 and 65, becomes,

$$Q = 3.34LZ^{1.47}\left(1 + \frac{1}{5}\sqrt{\frac{HD}{d_1Z}}\right)\left(1 + 1.2\frac{D}{Z}\right)\left(1 + 0.56\frac{H^2}{d^2}\right) \tag{41}$$

If there are end contractions, the Francis method of correction (page 67) may be used. Formula (41) applies to all submerged rectangular sharp-crested weirs fo all channel conditions. It gives results agreeing within approximately 3 per cent. with the experiments of Francis, Fteley and Stearns, and Bazin, and it seems reasonable to believe that equally good results may be expected if due care is taken in making measure-

ments, and the depth of submergence (D) is measured below all turbulence caused by the overfalling water.

When D is measured in the trough of the standing wave, it is believed that the discharge may be represented approximately by the formula

$$Q = 3.34LZ^{1.47}\left(1 + 1.2\frac{D}{Z}\right)\left(1 + 0.56\frac{H^2}{d^2}\right) \tag{42}$$

This formula, however, lacks experimental verification.

A submerged-weir formula to be generally applicable should take into consideration the dimensions of the channels both above and below the weir.

The formulas of Francis, Fteley and Stearns, and Herschel which do not consider the effect of the size of the channel give results varying in places by more than 25 per cent. from the results of the Bazin experiments. These formulas are complicated by the requirement of a separate velocity of approach correction, which renders their solution very difficult. The apparent simple form of the formulas as given without the velocity of approach correction is deceiving.

Additional experimental data with various heights of weirs and dimensions of channels, with values of H and D varying through as wide a range as possible, are needed to assist in a more comprehensive study of the subject of flow over submerged weirs. Such experiments should give the head of submergence in the trough of the standing wave as well as at a point in the channel where the normal condition of flow has been established. It is important also that the slope or grade of the lower channel should be given, in order that the head of submergence taken at one point may be transferred to a point farther up or down the channel if desired.

In Appendix A various tables (Tables 108 to 111 inclusive) with discussions of same are given for the purpose of showing the extent to which the submerged-weir formulas given in the preceding pages agree with the available experimental data. These tables cover practically the entire range of the experiments by Francis, Fteley and Stearns, and Bazin. The accuracy and general applicability of the author's formula can best be determined by an examination of these tabulated results, and the author makes no claim for his formula which cannot be substantiated by them.

The solution of the formula may be simplified by the use of tables. Table 33, page 98, gives values of

$$3.34\, Z^{1.47}$$

Table 34, page 103, gives values of

$$1 + 0.56 \frac{H^2}{d^2}$$

and Table 36, page 109, gives values of

$$\left(1 + \frac{1}{5}\sqrt{\frac{HD}{d_1 Z}}\right)\left(1 + 1.2\frac{D}{Z}\right)$$

corresponding to different values of $\frac{H}{d_1}$ and $\frac{D}{Z}$. The discharge is the product of these three quantities and the length of the weir. By careful interpolation values may be taken from Table 36 that will be accurate within 1 per cent. of error, which is close enough for ordinary purposes when the probable limits in accuracy of the formula are considered.

In the form given, formula (41) is directly applicable to problems in which the discharge over the weir is to be determined. In certain problems it is desired to know the amount that the elevation of water surface in a channel will be raised by the construction of a submerged weir of a given height. In this case Q is given, D is the depth of water in the channel minus the height of weir and d_1 may be readily obtained. Z is unknown, as are also H and d which depend upon Z for their values. The formula can best be solved by assuming successive values for Z until a value is found which satisfies the equation. By using the tables above referred to the successive solutions will be much simplified.

A similar method is necessary in solving problems where it is desired to determine the height of submerged weir necessary to raise the elevation of water surface in a channel a given amount. In this case Q and Z are given, and d and d_1 may be readily obtained. H and $D = H - Z$ are the only unknown quantities and the equation may be solved by assuming successive values of H. With H determined, the height of weir is equal to the depth of water in the channel above the weir minus H.

V-Notch Weirs

V-notch weirs may be used to advantage in measuring discharges which do not exceed from 15 to 20 cubic feet per second.

Using the nomenclature indicated in Fig. 28, the theoretical discharge is given by the formula

$$Q = \frac{4}{15}\sqrt{2g}\,LH^{3/2} \tag{43}$$

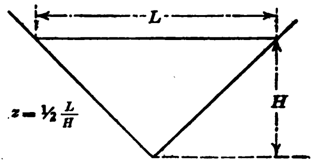


FIG. 28.—V-notch weir.

If z represents the slope which the side of the weir makes with the vertical then

$$L = 2\,zH \text{ and}$$

$$Q = \frac{8}{15}\sqrt{2g}\,zH^{5/2} \tag{44}$$

For a right-angled notch z becomes unity and combining a coefficient of discharge with the constant part (assuming g to be a constant) of the above equation, the formula for discharge over a right-angled V-notch weir with sharp edges may be written

$$Q = CH^{5/2} \tag{45}$$

A more general form of this expression is

$$Q = C'H^n \tag{46}$$

The author has made a thorough investigation[1] of the above formula based upon the results of experiments at the University of Michigan,[2] supplemented by experiments by Thompson[3] and Barr.[4] From the University of Michigan experiments the author deduced the following formula, as representing the mean of the experimental results:

$$Q = 2.52\,H^{2.47} \tag{47}$$

As the three sets of experiments are not entirely consistent with each other, Table 31, page 86, giving a summary of the results of all of the experiments investigated is reproduced.

[1] *University of Michigan Technic*, October, 1916, pp. 190–195.

[2] *University of Michigan Technic*, October, 1916, p. 191.

[3] PROF. JAMES THOMPSON: Papers in Physics and Engineering, p. 46, Cambridge.

[4] JAMES BARR: Experiments upon the Flow of Water over Triangular Notches. *Engineering*, April 8 and 15, 1910.

It will be noted in each set of experiments that the value of C gradually decreases as the head increases. This indicates that an exponent of H less than 2.5 should give a more nearly constant coefficient. From column 7 it will be seen that an exponent of 2.47 for the University of Michigan experiments gives a nearly constant value of C', approximately 2.52, as already given in formula (47).

TABLE 31.—VALUES OF COEFFICIENTS COMPUTED FROM EXPERIMENTS ON RIGHT-ANGLED V-NOTCHED WEIRS, FOR FORMULAS $Q = CH^{2.5}$ AND $Q = C'H^{2.47}$

H in feet	Thompson's experiments		Barr's experiments		University of Michigan experiments	
	C	C'	C	C'	C	C'
.15	2.570	2.428	2.588	2.445	2.672	2.524
.20	2.562	2.441	2.566	2.446	2.646	2.521
.25	2.555	2.451	2.551	2.447	2.626	2.519
.30	2.550	2.460	2.539	2.449	2.610	2.518
.35	2.545	2.466	2.530	2.451	2.597	2.517
.40	2.540	2.471	2.522	2.454	2.587	2.517
.45	2.537	2.477	2.517	2.458	2.579	2.518
.50	2.534	2.482	2.512	2.460	2.572	2.519
.55	2.532	2.487	2.508	2.463	2.565	2.519
.60	2.530	2.491	2.504	2.465	2.560	2.520
.65			2.500	2.468	2.554	2.521
.70			2.497	2.470	2.549	2.522
.75			2.494	2.473	2.544	2.522
.80			2.492	2.475	2.540	2.523
.85			2.490	2.478	2.534	2.523
.90					2.530	2.523
1.0					2.523	2.523
1.1					2.515	2.522
1.2					2.509	2.523
1.3					2.503	2.523
1.4					2.498	2.523
1.5					2.493	2.523
1.6					2.488	2.523
1.7					2.484	2.524
1.8					2.480	2.524

An exponent of 2.478 for Barr's experiments will give a nearly constant coefficient equal to approximately 2.48.

The exponent of H that would best fit Thompson's experiments is nearly 2.49. There is however but little information available regarding the manner in which these experiments were performed and as they cover such a narrow range of discharge they are not entitled to the weight of the other experiments.

A very careful investigation was carried on by Barr to determine the effect of roughness of the upstream surface of the notch plate. Barr's original experiments were performed with notches cut in smooth brass plates. To determine the effect that roughness of the upstream face had upon discharge the surface was varnished, and dusted with emery before the varnish dried. The weir with the rough face gave discharges approximately 2 per cent. greater than the weir with the smooth face. The effect of this roughness is apparently to reduce the vertical component of the velocity of the water approaching the weir from below crest level and so also to reduce crest contraction.

The weir for the University of Michigan experiments was cut from a steel plate ¼ inch thick, the upstream edge being a sharp right angle, and the lower edge beveled to make the crest of the weir ⅛ inch thick.

It will be observed from columns 5 and 7 of Table 31 that the values of C' are about 2 per cent. greater for the University of Michigan experiments than for Barr's experiments. This may be accounted for by ~~the effect~~ of roughness of the upstream surface of the weir plate as observed by Barr. The plate used in the University of Michigan experiments was of ordinary commercial steel plate and undoubtedly very much rougher than the smooth brass plate used in the Barr experiments. Assuming that this explanation accounts for the 2 per cent. discrepancy the two sets of experiments give results varying by less than 1 per cent. throughout.

Table 37, page 110, gives discharges over right-angled V-notch weirs by the formula $Q = 2.52H^{2.47}$, for heads from 0 to 1.5 feet, with intervals of 0.001 feet.

There are no data for determining the effect of velocity of approach on V-notch weirs. Ordinarily this correction is insignificant as the cross-sectional area of the channel above the weir is much greater than the area of the weir opening. By assuming that the conditions for rectangular weirs (pages

69 to 71) hold for triangular weirs, the formula with velocity of approach correction may be written approximately

$$Q = 2.52H^{2.47}\left(1 + 0.23\frac{H^4}{A^2}\right) \tag{48}$$

in which A is the area of the channel of approach.

There are but few experimental data for discharge over V-notch weirs not right-angled. Assuming, however, the same coefficient of discharge as for right-angled notches, the general formula for all V-notch weirs becomes

$$Q = 2.52zH^{2.47} \tag{49}$$

In most cases a right-angled notch can be used as readily as any other. It should always be used when practicable, as the formula of discharge for such weirs is based upon more accurate experimental knowledge than for notches of other angles. The right-angled notch, moreover, has the advantage of being simpler to construct.

Trapezoidal Weirs

The discharge over a trapezoidal weir is commonly considered as the combined discharge of a rectangular weir of length L', Fig. 29, and a V-notch weir with side slopes $\frac{b}{H} = z$. Under

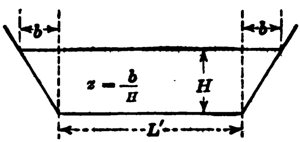


FIG. 29.—Trapezoidal weir.

this assumption, combining formulas (22) and (47), pages 73 and 85, the formula for discharge over sharp-crested trapezoidal weirs with end contractions, not including velocity of approach correction, becomes

$$Q = 3.34L'H^{1.47} + 2.52zH^{2.47}$$

or

$$Q = 3.34H^{1.47}(L' + 0.75zH) \tag{50}$$

Formula (50) will unquestionably give too great a discharge, since the contractions at the sides will be greater for a long weir than for the V-notch weir. The author submits the following

formula for trapezoidal weirs, with end contractions and velocity of approach correction, which must be considered as a rough approximation since it is entirely lacking in experimental verification:

$$Q = 3.34H^{1.47}(L' + 0.75zH - 0.2H)\left[1 + 0.56\left(\frac{HL}{A}\right)^2\right] \quad (51)$$

If $z = 0$ this equation reduces to the ordinary weir formula, with the Francis correction for end contractions. Formula (51) should not be used where L' is less than $2H$.

Cippoletti Weirs.—From a study of the Francis experiments, Cippoletti, an Italian engineer, concluded that a value of z of 0.25 would approximately offset the effect of end contractions of a rectangular weir and give a formula of the form

$$Q = CLH^{3/2} \quad (2)$$

Cippoletti finally chose a value of $3.3\frac{2}{3}$ for C, having concluded that the value 3.33 obtained by Francis was too small. The reasons for this choice are not clear. It is, however, this value of C which has been quite generally adopted for Cippoletti weirs, and the formula which has been extensively used is

$$Q = 3.3\tfrac{2}{3}LH^{3/2} \quad (52)$$

in which L is the measured length of crest of weir.

Experiments by Flinn and Dyer[1] and others indicate that the value of C increased as H decreases, suggesting the need of either a greater slope for the sides of the weir or an exponent of H less than 1.5. Table 38, page 113, gives values of Q for Cippoletti weirs by formula (52).

Formula (52) should not be used when a high degree of accuracy is required. No method of correcting for velocity of approach is suggested. It was intended by Cippoletti that the Francis velocity-of-approach correction should be used.

The author believes that his formula for rectangular weirs, written in the form

$$Q = 3.34LH^{1.47}\left[1 + 0.56\left(\frac{HL}{A}\right)^2\right] \quad (7a)$$

will apply more readily and accurately to Cippoletti weirs than formula (52). The sloping sides are introduced solely to offset

[1] A. D. Flinn and C. W. D. Dyer: The Cippoletti Trapezoidal Weir. *Trans.* Amer. Soc. Civ. Eng., vol. 32.

the effects of end contractions and the conditions become similar to those for a weir with end contractions suppressed.

Assuming formula (51), and the Francis correction for end contractions (formula (4)), in order that the slope of the sides of the Cippoletti weir may just offset the effect of end contractions, the following relation must exist:

$$0.75zH = 0.2H$$

or

$$z = 0.267$$

which is very close to 0.25, the value used by Cippoletti.

Weirs with Crest Not Level

When the crest of a weir is not level, Fig. 30, if the inclination is slight, the discharge will be given quite accurately by the formula for rectangular weirs, using the mean head H_m. A more precise formula may be obtained from the expression

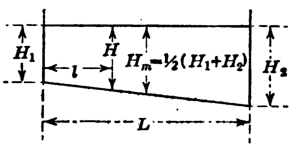


FIG. 30.—Weir with crest not level.

$$Q = 3.34 \left((1 + 0.56 \frac{H_m^2}{d^2}\right) \int_0^L H^{1.47} dl$$

in which

$$H = H_1 + \frac{H_2 - H_1}{L} l$$

The resulting formula for discharge over a weir with crest inclined and vertical sides is

$$Q = \frac{1.352\, L(H_2^{2.47} - H_1^{2.47})}{H_2 - H_1}\left(1 + 0.56 \frac{H_m^2}{d^2}\right) \tag{53}$$

If there are end contractions, L' being the measured length and L the corrected length of weir

$$L = L' - 0.1\,(H_1 + H_2) \tag{54}$$

Determination of Mean Discharge from Several Observations

In measuring the discharge over a weir greater accuracy may usually be obtained by making several measurements of head at short intervals of time apart. These measurements will not give quite constant values of H, even though uniform conditions of flow exist, owing to surge in the channel and unavoidable errors in measurement. Even under favorable conditions when great care is taken, heads measured in a stilling-box, by means of a hook gage, may show considerable variation.

Consider n observations to be made in a total time T at intervals of t_1, t_2, t_3, . . . t_n. The measured heads corresponding to these intervals are H_1, H_2, H_3, . . . H_n; H_m being the mean head.

Assuming formula (7), page 72, for rectangular weirs, the mean discharge in cubic feet per second for any number of observations is

$$Q = \frac{3.34\,L}{2T}\left[t_1 H_1^{1.47} + (t_1 + t_2)\,H_2^{1.47} + (t_2 + t_3)H_3^{1.47} \;.\;.\;.\;. + t_{n-1}H_n^{1.47}\right]\left(1 + 0.56\,\frac{H_m^2}{d^2}\right) \qquad (55)$$

If the time intervals are equal

$$Q = \frac{3.34\,L}{n-1}\left(\tfrac{1}{2}H_1^{1.47} + H_2^{1.47} + H_3^{1.47} \;.\;.\;.\;. + \tfrac{1}{2}H_n^{1.47}\right)\left(1 + 0.56\,\frac{H_m^2}{d^2}\right) \qquad (56)$$

When the fluctuations in head do not have a range of more than 0.02 feet the error from using the formula

$$Q = 3.34LH_m^{1.47}\left(1 + 0.56\,\frac{H_m^2}{d^2}\right)$$

is insignificant.

When a weir is used for obtaining continuous-discharge records of a stream with fluctuating stage, to obtain the mean daily flow from several different gage readings, the discharge should be computed for each reading, and the mean of these discharges, weighted to correspond to the proper time interval, should be taken. Formula (55) may be used for this purpose if preferred, or formula (56) providing that the same time interval is employed throughout. If there is much fluctuation in stage, an appreciable error will be introduced in using the mean head

for computing the discharge, the actual discharge being greater than that determined from the mean head where the head varies continuously in the same direction between observations. This is because the discharge varies faster than the head.

Choice of Weir for Maximum Accuracy

In selecting a weir for the accurate measurement of water, care should be taken to choose the weir best adapted to the particular conditions. Usually the quantity of water, or the limiting quantities if the flow fluctuates, may be determined approximately before beginning the measurement. The best weir for the purpose may then be selected, giving careful consideration to the following important points:

1. Owing to the tendency of the nappe to adhere to the down-stream face, weirs should not be used where the measured head is less than 0.2 feet.
2. In all cases the length of a rectangular weir should be at least three times the head.
3. The head on the weir should preferably not be greater than 1.5 feet.
4. The percentage of error in discharge resulting from a given error in measuring head decreases as the head increases. Greater accuracy may therefore be secured by selecting a weir of such dimensions as to have the discharge occur under the maximum head practicable, subject to the requirements of paragraphs 1, 2 and 3 above.

Table 41, page 127, giving the percentage of error in discharge, for different discharges and dimensions of weirs, resulting from various errors in measuring head, has been prepared to assist in the selection of the best weir for a given purpose. Of the weirs listed those given in bold type are recommended. The table is intended merely as a guide, however, and the engineer must use his judgment in selecting a weir which will best conform to the requirements of the four paragraphs given above.

One point brought out quite clearly by Table 41 is that right-angled V-notch weirs are preferable to weirs of any other type for measuring discharges below 1 cubic foot per second, and they are at least as accurate as any other weir for discharges up to 10 cubic feet per second. They are therefore particularly adapted to the measurement of fluctuating discharges where the maximum discharge does not greatly exceed 10 cubic feet per second.

TABLE 32.—1.47 POWERS OF NUMBERS

Number	.000	.001	.002	.003	.004	.005	.006	.007	.008	.009
.00	.0000	.0000	.0001	.0002	.0003	.0004	.0005	.0007	.0008	.0010
.01	.0011	.0013	.0015	.0017	.0019	.0021	.0023	.0025	.0027	.0030
.02	.0032	.0034	.0037	.0039	.0042	.0044	.0047	.0049	.0052	.0055
.03	.0058	.0061	.0063	.0066	.0069	.0072	.0075	.0079	.0082	.0085
.04	.0088	.0091	.0095	.0098	.0101	.0105	.0108	.0112	.0115	.0119
.05	.0122	.0126	.0130	.0133	.0137	.0141	.0145	.0148	.0152	.0156
.06	.0160	.0164	.0168	.0172	.0176	.0180	.0184	.0188	.0192	.0196
.07	.0201	.0205	.0209	.0213	.0218	.0222	.0226	.0231	.0235	.0240
.08	.0244	.0249	.0253	.0258	.0262	.0267	.0271	.0276	.0281	.0286
.09	.0290	.0295	.0300	.0305	.0309	.0314	.0319	.0324	.0329	.0334
.10	.0339	.0344	.0349	.0354	.0359	.0364	.0369	.0374	.0379	.0385
.11	.0390	.0395	.0400	.0406	.0411	.0416	.0421	.0427	.0432	.0438
.12	.0443	.0448	.0454	.0459	.0465	.0470	.0476	.0482	.0487	.0493
.13	.0498	.0504	.0510	.0515	.0521	.0527	.0533	.0538	.0544	.0550
.14	.0556	.0562	.0567	.0573	.0579	.0585	.0591	.0597	.0603	.0609
.15	.0615	.0621	.0627	.0633	.0639	.0645	.0652	.0658	.0664	.0670
.16	.0676	.0682	.0689	.0695	.0701	.0707	.0714	.0720	.0726	.0733
.17	.0739	.0746	.0752	.0758	.0765	.0771	.0778	.0784	.0791	.0797
.18	.0804	.0811	.0817	.0824	.0830	.0837	.0844	.0850	.0857	.0864
.19	.0871	.0877	.0884	.0891	.0898	.0904	.0911	.0918	.0925	.0932
.20	.0939	.0946	.0953	.0959	.0966	.0973	.0980	.0987	.0994	.1001
.21	.1009	.1016	.1023	.1030	.1037	.1044	.1051	.1058	.1066	.1073
.22	.1080	.1087	.1094	.1102	.1109	.1116	.1124	.1131	.1138	.1145
.23	.1153	.1160	.1168	.1175	.1182	.1190	.1197	.1205	.1212	.1220
.24	.1227	.1235	.1242	.1250	.1257	.1265	.1273	.1280	.1288	.1295
.25	.1303	.1311	.1319	.1326	.1334	.1342	.1349	.1357	.1365	.1373
.26	.1380	.1388	.1396	.1404	.1412	.1420	.1428	.1436	.1443	.1451
.27	.1459	.1467	.1475	.1483	.1491	.1499	.1507	.1515	.1523	.1531
.28	.1539	.1547	.1556	.1564	.1572	.1580	.1588	.1596	.1604	.1613
.29	.1621	.1629	.1637	.1645	.1654	.1662	.1670	.1679	.1687	.1695
.30	.1704	.1712	.1720	.1729	.1737	.1746	.1754	.1762	.1771	.1779
.31	.1788	.1796	.1805	.1813	.1822	.1830	.1839	.1847	.1856	.1865
.32	.1873	.1882	.1890	.1899	.1908	.1916	.1925	.1934	.1942	.1951
.33	.1960	.1969	.1977	.1986	.1995	.2004	.2013	.2021	.2030	.2039
.34	.2048	.2057	.2066	.2075	.2083	.2092	.2101	.2110	.2119	.2128
.35	.2137	.2146	.2155	.2164	.2173	.2182	.2191	.2200	.2209	.2218
.36	.2227	.2236	.2245	.2255	.2264	.2273	.2282	.2291	.2300	.2310
.37	.2319	.2328	.2337	.2346	.2356	.2365	.2374	.2384	.2393	.2402
.38	.2411	.2421	.2430	.2440	.2449	.2458	.2468	.2477	.2487	.2496
.39	.2505	.2515	.2524	.2534	.2543	.2553	.2562	.2572	.2581	.2591
.40	.2600	.2610	.2620	.2629	.2639	.2648	.2658	.2668	.2677	.2687
.41	.2696	.2706	.2716	.2726	.2735	.2745	.2755	.2764	.2774	.2784
.42	.2794	.2804	.2813	.2823	.2833	.2843	.2853	.2862	.2872	.2882
.43	.2892	.2902	.2912	.2922	.2932	.2942	.2951	.2961	.2971	.2981
.44	.2991	.3001	.3011	.3021	.3031	.3041	.3051	.3062	.3072	.3082
45	.3092	.3102	.3112	.3122	.3132	.3142	.3153	.3163	.3173	.3183
46	.3193	.3204	.3214	.3224	.3234	.3245	.3255	.3265	.3275	.3286
.47	.3296	.3306	.3317	.3327	.3337	.3348	.3358	.3368	.3379	.3389
.48	.3400	.3410	.3420	.3431	.3441	.3452	.3462	.3473	.3483	.3494
.49	.3504	.3515	.3525	.3536	.3546	.3556	.3567	.3578	.3589	.3599

TABLE 32 (*Continued*)

1.47 POWERS OF NUMBERS

Number	.000	.001	.002	.003	.004	.005	.006	.007	.008	.009
.50	.3610	.3620	.3631	.3642	.3652	.3663	.3674	.3684	.3695	.3706
.51	.3716	.3727	.3738	.3749	.3759	.3770	.3781	.3792	.3803	.3813
.52	.3824	.3835	.3846	.3857	.3868	.3878	.3889	.3900	.3911	.3922
.53	.3933	.3944	.3955	.3965	.3976	.3987	.3998	.4009	.4020	.4031
.54	.4042	.4053	.4064	.4075	.4086	.4097	.4108	.4119	.4131	.4142
.55	.4153	.4164	.4175	.4186	.4197	.4208	.4219	.4231	.4242	.4253
.56	.4264	.4275	.4287	.4298	.4309	.4320	.4331	.4343	.4354	.4365
.57	.4377	.4388	.4399	.4411	.4422	.4433	.4444	.4456	.4467	.4479
.58	.4490	.4501	.4513	.4524	.4536	.4547	.4558	.4570	.4581	.4593
.59	.4604	.4616	.4627	.4639	.4650	.4662	.4673	.4685	.4696	.4708
.60	.4719	.4731	.4743	.4754	.4766	.4777	.4789	.4801	.4812	.4824
.61	.4835	.4847	.4859	.4871	.4882	.4894	.4906	.4917	.4929	.4941
.62	.4952	.4964	.4976	.4988	.5000	.5011	.5023	.5035	.5047	.5059
.63	.5070	.5082	.5094	.5106	.5118	.5130	.5141	.5153	.5165	.5177
.64	.5189	.5201	.5213	.5225	.5237	.5249	.5261	.5273	.5285	.5297
.65	.5309	.5321	.5333	.5345	.5357	.5369	.5381	.5393	.5405	.5417
.66	.5429	.5441	.5453	.5465	.5478	.5490	.5502	.5514	.5526	.5538
.67	.5551	.5563	.5575	.5587	.5599	.5612	.5624	.5636	.5648	.5660
.68	.5673	.5685	.5697	.5710	.5722	.5734	.5747	.5759	.5771	.5783
.69	.5796	.5808	.5820	.5833	.5845	.5858	.5870	.5882	.5895	.5907
.70	.5920	.5932	.5944	.5957	.5969	.5982	.5994	.6007	.6019	.6032
.71	.6044	.6057	.6069	.6082	.6094	.6107	.6120	.6132	.6145	.6157
.72	.6170	.6183	.6195	.6208	.6220	.6233	.6246	.6259	.6271	.6284
.73	.6296	.6309	.6322	.6334	.6347	.6360	.6373	.6385	.6398	.6411
.74	.6424	.6436	.6449	.6462	.6475	.6488	.6500	.6513	.6526	.6539
.75	.6552	.6564	.6577	.6590	.6603	.6616	.6629	.6642	.6655	.6667
.76	.6680	.6693	.6706	.6719	.6732	.6745	.6758	.6771	.6784	.6797
.77	.6810	.6823	.6836	.6849	.6862	.6875	.6888	.6901	.6914	.6927
.78	.6940	.6953	.6967	.6980	.6993	.7006	.7019	.7032	.7045	.7058
.79	.7072	.7085	.7098	.7111	.7124	.7138	.7151	.7164	.7177	.7190
.80	.7204	.7217	.7230	.7243	.7256	.7270	.7283	.7296	.7310	.7323
.81	.7336	.7350	.7363	.7376	.7389	.7403	.7416	.7430	.7443	.7456
.82	.7470	.7483	.7497	.7510	.7523	.7537	.7550	.7564	.7577	.7591
.83	.7604	.7618	.7631	.7645	.7658	.7672	.7685	.7699	.7712	.7726
.84	.7739	.7753	.7766	.7780	.7793	.7807	.7821	.7834	.7848	.7861
.85	.7875	.7889	.7902	.7916	.7929	.7943	.7957	.7970	.7984	.7998
.86	.8012	.8025	.8039	.8053	.8066	.8080	.8094	.8107	.8121	.8135
.87	.8149	.8163	.8176	.8190	.8204	.8218	.8232	.8245	.8259	.8263
.88	.8287	.8301	.8314	.8328	.8342	.8356	.8370	.8384	.8398	.8412
.89	.8426	.8440	.8453	.8467	.8481	.8495	.8509	.8523	.8537	.8551
.90	.8565	.8579	.8593	.8607	.8621	.8635	.8649	.8663	.8677	.8691
.91	.8706	.8720	.8734	.8748	.8762	.8776	.8790	.8804	.8818	.8832
.92	.8846	.8861	.8875	.8889	.8903	.8917	.8931	.8946	.8960	.8974
.93	.8988	.9002	.9017	.9031	.9045	.9059	.9073	.9088	.9102	.9116
.94	.9131	.9145	.9159	.9174	.9188	.9202	.9216	.9231	.9245	.9259
.95	.9274	.9288	.9302	.9317	.9331	.9346	.9360	.9374	.9389	.9403
.96	.9418	.9432	.9446	.9461	.9475	.9490	.9504	.9519	.9533	.9548
.97	.9562	.9577	.9591	.9606	.9620	.9635	.9649	.9664	.9678	.9693
.98	.9707	.9722	.9737	.9751	.9766	.9780	.9795	.9810	.9824	.9839
.99	.9853	.9868	.9883	.9897	.9912	.9927	.9941	.9956	.9971	.9985

TABLE 32 (*Continued*)

1.47 POWERS OF NUMBERS

Number	.000	.001	.002	.003	.004	.005	.006	.007	.008	.009
1.00	1.0000	1.0015	1.0029	1.0044	1.0059	1.0074	1.0088	1.0103	1.0118	1.0133
1.01	1.0147	1.0162	1.0177	1.0192	1.0207	1.0221	1.0236	1.0251	1.0266	1.0281
1.02	1.0295	1.0310	1.0325	1.0340	1.0355	1.0370	1.0385	1.0399	1.0414	1.0429
1.03	1.0444	1.0459	1.0474	1.0489	1.0504	1.0519	1.0534	1.0549	1.0564	1.0579
1.04	1.0594	1.0609	1.0624	1.0639	1.0654	1.0669	1.0684	1.0699	1.0714	1.0729
1.05	1.0744	1.0759	1.0774	1.0789	1.0804	1.0819	1.0834	1.0849	1.0864	1.0879
1.06	1.0894	1.0909	1.0925	1.0940	1.0955	1.0970	1.0985	1.1000	1.1015	1.1031
1.07	1.1046	1.1061	1.1076	1.1091	1.1107	1.1122	1.1137	1.1152	1.1167	1.1183
1.08	1.1198	1.1213	1.1228	1.1244	1.1259	1.1274	1.1290	1.1305	1.1320	1.1335
1.09	1.1351	1.1366	1.1381	1.1397	1.1412	1.1427	1.1442	1.1458	1.1473	1.1489
1.10	1.1504	1.1519	1.1535	1.1550	1.1566	1.1581	1.1596	1.1612	1.1627	1.1643
1.11	1.1658	1.1673	1.1689	1.1704	1.1720	1.1735	1.1751	1.1766	1.1782	1.1797
1.12	1.1813	1.1828	1.1844	1.1859	1.1875	1.1890	1.1906	1.1921	1.1937	1.1953
1.13	1.1968	1.1984	1.1999	1.2015	1.2030	1.2045	1.2061	1.2076	1.2092	1.2108
1.14	1.2124	1.2140	1.2155	1.2171	1.2187	1.2202	1.2218	1.2234	1.2249	1.2265
1.15	1.2281	1.2297	1.2312	1.2328	1.2344	1.2359	1.2375	1.2391	1.2407	1.2422
1.16	1.2438	1.2454	1.2470	1.2486	1.2501	1.2517	1.2533	1.2549	1.2565	1.2580
1.17	1.2596	1.2612	1.2628	1.2643	1.2659	1.2675	1.2691	1.2707	1.2723	1.2739
1.18	1.2755	1.2771	1.2786	1.2802	1.2818	1.2834	1.2850	1.2866	1.2882	1.2898
1.19	1.2914	1.2930	1.2946	1.2962	1.2978	1.2994	1.3010	1.3026	1.3042	1.3058
1.20	1.3074	1.3090	1.3106	1.3122	1.3138	1.3154	1.3170	1.3186	1.3202	1.3218
1.21	1.3234	1.3250	1.3266	1.3282	1.3299	1.3315	1.3331	1.3347	1.3363	1.3379
1.22	1.3395	1.3411	1.3427	1.3444	1.3460	1.3476	1.3492	1.3508	1.3525	1.3541
1.23	1.3557	1.3573	1.3589	1.3606	1.3622	1.3638	1.3654	1.3670	1.3687	1.3703
1.24	1.3719	1.3736	1.3752	1.3768	1.3784	1.3801	1.3817	1.3833	1.3850	1.3866
1.25	1.3882	1.3899	1.3915	1.3931	1.3947	1.3964	1.3980	1.3997	1.4013	1.4029
1.26	1.4046	1.4062	1.4079	1.4095	1.4111	1.4128	1.4144	1.4161	1.4177	1.4193
1.27	1.4210	1.4226	1.4242	1.4259	1.4276	1.4292	1.4309	1.4325	1.4342	1.4358
1.28	1.4375	1.4391	1.4408	1.4424	1.4441	1.4457	1.4474	1.4490	1.4507	1.4524
1.29	1.4540	1.4557	1.4573	1.4590	1.4606	1.4623	1.4640	1.4656	1.4673	1.4690
1.30	1.4706	1.4723	1.4739	1.4756	1.4773	1.4789	1.4806	1.4823	1.4839	1.4856
1.31	1.4873	1.4889	1.4906	1.4923	1.4940	1.4956	1.4973	1.4990	1.5006	1.5023
1.32	1.5040	1.5057	1.5073	1.5090	1.5107	1.5124	1.5140	1.5157	1.5174	1.5191
1.33	1.5208	1.5224	1.5241	1.5258	1.5275	1.5292	1.5308	1.5325	1.5342	1.5359
1.34	1.5376	1.5393	1.5410	1.5427	1.5444	1.5461	1.5477	1.5494	1.5511	1.5528
1.35	1.5545	1.5562	1.5579	1.5596	1.5613	1.5630	1.5647	1.5664	1.5681	1.5698
1.36	1.5715	1.5732	1.5749	1.5766	1.5783	1.5800	1.5817	1.5834	1.5851	1.5868
1.37	1.5885	1.5902	1.5919	1.5936	1.5953	1.5970	1.5987	1.6004	1.6021	1.6038
1.38	1.6055	1.6073	1.6090	1.6107	1.6124	1.6141	1.6158	1.6175	1.6192	1.6210
1.39	1.6227	1.6244	1.6261	1.6278	1.6296	1.6313	1.6330	1.6347	1.6364	1.6382
1.40	1.6399	1.6416	1.6433	1.6450	1.6468	1.6485	1.6502	1.6519	1.6537	1.6554
1.41	1.6571	1.6588	1.6606	1.6623	1.6640	1.6658	1.6675	1.6692	1.6710	1.6727
1.42	1.6744	1.6762	1.6779	1.6796	1.6813	1.6831	1.6848	1.6866	1.6883	1.6900
1.43	1.6918	1.6935	1.6953	1.6970	1.6987	1.7005	1.7022	1.7040	1.7057	1.7075
1.44	1.7092	1.7109	1.7127	1.7144	1.7162	1.7179	1.7197	1.7214	1.7232	1.7249
1.45	1.7267	1.7284	1.7302	1.7319	1.7337	1.7354	1.7372	1.7389	1.7407	1.7425
1.46	1.7442	1.7460	1.7477	1.7495	1.7512	1.7530	1.7548	1.7565	1.7583	1.7600
1.47	1.7618	1.7636	1.7653	1.7671	1.7689	1.7706	1.7724	1.7741	1.7759	1.7777
1.48	1.7795	1.7812	1.7830	1.7848	1.7865	1.7883	1.7901	1.7918	1.7936	1.7954
1.49	1.7972	1.7989	1.8007	1.8025	1.8042	1.8060	1.8078	1.8096	1.8113	1.8131

TABLE 32 (*Continued*)

1.47 POWERS OF NUMBERS

Number	.000	.001	.002	.003	.004	.005	.006	.007	.008	.009
1.50	1.8149	1.8167	1.8185	1.8202	1.8220	1.8238	1.8255	1.8273	1.8291	1.8309
1.51	1.8327	1.8345	1.8363	1.8381	1.8399	1.8416	1.8434	1.8452	1.8470	1.8488
1.52	1.8506	1.8524	1.8542	1.8560	1.8578	1.8595	1.8613	1.8631	1.8649	1.8667
1.53	1.8685	1.8703	1.8721	1.8739	1.8757	1.8775	1.8793	1.8811	1.8829	1.8847
1.54	1.8865	1.8883	1.8901	1.8919	1.8937	1.8955	1.8973	1.8991	1.9009	1.9027
1.55	1.9045	1.9063	1.9081	1.9100	1.9118	1.9136	1.9154	1.9172	1.9190	1.9208
1.56	1.9226	1.9244	1.9262	1.9281	1.9299	1.9317	1.9335	1.9353	1.9371	1.9389
1.57	1.9408	1.9426	1.9444	1.9462	1.9480	1.9499	1.9517	1.9535	1.9553	1.9571
1.58	1.9590	1.9608	1.9626	1.9644	1.9662	1.9681	1.9699	1.9717	1.9736	1.9754
1.59	1.9772	1.9790	1.9809	1.9827	1.9845	1.9864	1.9882	1.9900	1.9918	1.9937
1.60	1.9955	1.9974	1.9992	2.0010	2.0028	2.0047	2.0065	2.0084	2.0102	2.0120
1.61	2.0139	2.0157	2.0176	2.0194	2.0212	2.0231	2.0249	2.0268	2.0286	2.0305
1.62	2.0323	2.0341	2.0360	2.0378	2.0397	2.0415	2.0434	2.0452	2.0471	2.0489
1.63	2.0508	2.0526	2.0545	2.0563	2.0582	2.0600	2.0619	2.0637	2.0656	2.0674
1.64	2.0693	2.0711	2.0730	2.0748	2.0767	2.0786	3.0804	2.0823	2.0841	2.0860
1.65	2.0879	2.0897	2.0916	2.0934	2.0953	2.0972	2.0990	2.1009	2.1028	2.1046
1.66	2.1065	2.1084	2.1102	2.1121	2.1140	2.1158	2.1177	2.1196	2.1214	2.1233
1.67	2.1252	2.1270	2.1289	2.1308	2.1327	2.1345	2.1364	2.1383	2.1401	2.1420
1.68	2.1439	2.1458	2.1476	2.1495	2.1514	2.1533	2.1552	2.1570	2.1589	2.1608
1.69	2.1627	2.1646	2.1664	2.1683	2.1702	2.1721	2.1740	2.1759	2.1777	2.1796
1.70	2.1815	2.1834	2.1853	2.1872	2.1891	2.1910	2.1929	2.1947	2.1966	2.1985
1.71	2.2004	2.2023	2.2042	2.2061	2.2080	2.2099	2.2118	2.2137	2.2156	2.2175
1.72	2.2194	2.2213	2.2232	2.2251	2.2270	2.2289	2.2308	2.2327	2.2346	2.2365
1.73	2.2384	2.2403	2.2422	2.2441	2.2460	2.2479	2.2498	2.2517	2.2536	2.2555
1.74	2.2574	2.2593	2.2612	2.2631	2.2650	2.2669	2.2689	2.2708	2.2727	2.2746
1.75	2.2765	2.2784	2.2803	2.2822	2.2841	2.2860	2.2880	2.2899	2.2918	2.2937
1.76	2.2956	2.2976	2.2995	2.3014	2.3033	2.3052	2.3072	2.3091	2.3110	2.3129
1.77	2.3148	2.3168	2.3187	2.3206	2.3225	2.3244	2.3264	2.3283	2.3302	2.3322
1.78	2.3341	2.3360	2.3380	2.3399	2.3418	2.3437	2.3457	2.3476	2.3495	2.3515
1.79	2.3534	2.3553	2.3573	2.3592	2.3611	2.3630	2.3650	2.3669	2.3689	2.3708
1.80	2.3727	2.3747	2.3766	2.3786	2.3805	2.3824	2.3844	2.3863	2.3883	2.3902
1.81	2.3922	2.3941	2.3960	2.3980	2.3999	2.4019	2.4039	2.4058	2.4077	2.4097
1.82	2.4116	2.4136	2.4155	2.4175	2.4194	2.4214	2.4233	2.4253	2.4272	2.4292
1.83	2.4311	2.4331	2.4350	2.4370	2.4389	2.4409	2.4428	2.4448	2.4467	2.4487
1.84	2.4507	2.4526	2.4546	2.4565	2.4585	2.4605	2.4624	2.4644	2.4663	2.4683
1.85	2.4703	2.4722	2.4742	2.4761	2.4781	2.4801	2.4820	2.4840	2.4860	2.4879
1.86	2.4899	2.4919	2.4939	2.4958	2.4978	2.4998	2.5017	2.5037	2.5057	2.5076
1.87	2.5096	2.5116	2.5136	2.5155	2.5175	2.5195	2.5215	2.5234	2.5254	2.5274
1.88	2.5294	2.5314	2.5333	2.5353	2.5373	2.5393	2.5413	2.5432	2.5452	2.5472
1.89	2.5492	2.5512	2.5531	2.5551	2.5571	2.5591	2.5611	2.5631	2.5650	2.5670
1.90	2.5690	2.5710	2.5730	2.5750	2.5770	2.5790	2.5810	2.5830	2.5849	2.5869
1.91	2.5889	2.5909	2.5929	2.5949	2.5969	2.5989	2.6009	2.6029	2.6049	2.6069
1.92	2.6089	2.6109	2.6129	2.6149	2.6169	2.6189	2.6209	2.6229	2.6249	2.6269
1.93	2.6289	2.6309	2.6329	2.6349	2.6369	2.6389	2.6409	2.6429	2.6449	2.6469
1.94	2.6489	2.6509	2.6529	2.6550	2.6570	2.6590	2.6610	2.6630	2.6650	2.6670
1.95	2.6690	2.6710	2.6730	2.6751	2.6771	2.6791	2.6811	2.6831	2.6851	2.6871
1.96	2.6892	2.6912	2.6932	2.6952	2.6972	2.6993	2.7013	2.7033	2.7053	2.7073
1.97	2.7094	2.7114	2.7134	2.7154	2.7174	2.7195	2.7215	2.7235	2.7255	2.7276
1.98	2.7296	2.7316	2.7336	2.7357	2.7377	2.7397	2.7418	2.7438	2.7458	2.7479
1.99	2.7499	2.7519	2.7539	2.7560	2.7580	2.7600	2.7621	2.7641	2.7661	2.7682

TABLE 32 (*Concluded*)

1.47 POWERS OF NUMBERS

Number	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
2.0	2.770	2.791	2.811	2.832	2.852	2.873	2.893	2.914	2.935	2.955
2.1	2.976	2.997	3.018	3.039	3.060	3.081	3.102	3.123	3.144	3.166
2.2	3.187	3.208	3.230	3.251	3.272	3.294	3.315	3.337	3.359	3.380
2.3	3.402	3.424	3.446	3.468	3.490	3.511	3.533	3.555	3.578	3.600
2.4	3.622	3.644	3.666	3.688	3.711	3.733	3.756	3.778	3.801	3.823
2.5	3.846	3.868	3.891	3.914	3.937	3.959	3.982	4.005	4.028	4.051
2.6	4.074	4.097	4.120	4.143	4.166	4.190	4.213	4.236	4.260	4.283
2.7	4.306	4.330	4.353	4.377	4.400	4.424	4.448	4.471	4.495	4.519
2.8	4.543	4.567	4.591	4.615	4.639	4.663	4.687	4.711	4.735	4.759
2.9	4.783	4.808	4.832	4.856	4.881	4.905	4.930	4.954	4.979	5.003
3.0	5.028	5.052	5.077	5.102	5.127	5.151	5.176	5.201	5.226	5.251
3.1	5.276	5.301	5.326	5.351	5.376	5.402	5.427	5.452	5.477	5.503
3.2	5.528	5.553	5.579	5.604	5.629	5.655	5.681	5.707	5.732	5.758
3.3	5.784	5.810	5.835	5.861	5.887	5.913	5.939	5.965	5.991	6.017
3.4	6.043	6.070	6.096	6.122	6.148	6.174	6.201	6.227	6.254	6.280
3.5	6.306	6.333	6.360	6.386	6.413	6.439	6.466	6.493	6.519	6.546
3.6	6.573	6.600	6.627	6.654	6.681	6.708	6.735	6.762	6.789	6.816
3.7	6.843	6.870	6.898	6.925	6.952	6.980	7.007	7.034	7.062	7.089
3.8	7.117	7.144	7.172	7.200	7.227	7.255	7.283	7.310	7.338	7.366
3.9	7.394	7.422	7.450	7.478	7.506	7.534	7.562	7.590	7.618	7.646
4.0	7.674	7.702	7.731	7.759	7.787	7.816	7.844	7.872	7.901	7.929
4.1	7.958	7.986	8.015	8.044	8.072	8.101	8.130	8.158	8.187	8.216
4.2	8.245	8.274	8.303	8.331	8.360	8.389	8.418	8.448	8.477	8.506
4.3	8.535	8.564	8.593	8.623	8.652	8.681	8.711	8.740	8.769	8.799
4.4	8.828	8.858	8.887	8.917	8.947	8.976	9.006	9.036	9.065	9.095
4.5	9.125	9.155	9.185	9.214	9.244	9.274	9.304	9.334	9.364	9.394
4.6	9.424	9.455	9.485	9.515	9.545	9.575	9.606	9.636	9.666	9.697
4.7	9.727	9.758	9.788	9.819	9.849	9.880	9.910	9.941	9.972	10.002
4.8	10.033	10.064	10.094	10.125	10.156	10.187	10.218	10.249	10.280	10.311
4.9	10.342	10.373	10.404	10.435	10.466	10.497	10.528	10.560	10.591	10.622
5.0	10.653	10.685	10.716	10.747	10.779	10.810	10.842	10.873	10.905	10.936
5.1	10.968	11.000	11.031	11.063	11.095	11.126	11.158	11.190	11.222	11.254
5.2	11.286	11.318	11.349	11.381	11.413	11.445	11.478	11.510	11.542	11.574
5.3	11.606	11.638	11.671	11.703	11.735	11.767	11.800	11.832	11.864	11.897
5.4	11.929	11.962	11.994	12.027	12.060	12.092	12.125	12.157	12.190	12.223
5.5	12.256	12.288	12.321	12.354	12.387	12.420	12.453	12.486	12.519	12.552
5.6	12.585	12.618	12.651	12.684	12.717	12.750	12.783	12.816	12.850	12.883
5.7	12.916	12.950	12.983	13.016	13.050	13.083	13.117	13.150	13.184	13.217
5.8	13.251	13.284	13.318	13.352	13.385	13.419	13.453	13.487	13.520	13.554
5.9	13.588	13.622	13.656	13.690	13.724	13.758	13.792	13.826	13.860	13.894
6.0	13.928	13.962	13.996	14.030	14.064	14.099	14.133	14.167	14.202	14.236
6.1	14.270	14.305	14.339	14.374	14.408	14.443	14.477	14.512	14.546	14.581
6.2	14.616	14.650	14.685	14.720	14.754	14.789	14.824	14.859	14.894	14.929
6.3	14.963	14.998	15.033	15.068	15.103	15.138	15.173	15.208	15.243	15.279
6.4	15.314	15.349	15.384	15.420	15.455	15.490	15.525	15.561	15.596	15.632
6.5	15.667	15.702	15.738	15.773	15.809	15.844	15.880	15.916	15.951	15.987
6.6	16.023	16.058	16.094	16.130	16.166	16.201	16.237	16.273	16.309	16.345
6.7	16.381	16.417	16.453	16.489	16.525	16.561	16.597	16.633	16.669	16.705
6.8	16.741	16.778	16.814	16.850	16.886	16.923	16.959	16.995	17.032	17.068
6.9	17.104	17.141	17.177	17.214	17.250	17.287	17.324	17.360	17.397	17.433

Table 33.—Discharge in Cubic Feet per Second per Foot of Length, Over Sharp-crested Weirs, Without Velocity of Approach Correction, by the Formula $Q = 3.34\ H^{1.47}$

Head in feet	.000	.001	.002	.003	.004	.005	.006	.007	.008	.009
.00	.0000	.0001	.0004	.0007	.0010	.0014	.0018	.0023	.0028	.0033
.01	.0038	.0044	.0050	.0056	.0063	.0070	.0077	.0084	.0091	.0098
.02	.0106	.0114	.0122	.0131	.0139	.0147	.0155	.0164	.0174	.0183
.03	.0193	.0202	.0212	.0222	.0232	.0242	.0252	.0262	.0273	.0283
.04	.0294	.0305	.0316	.0327	.0338	.0350	.0361	.0373	.0385	.0397
.05	.0409	.0421	.0433	.0445	.0457	.0470	.0483	.0495	.0508	.0521
.06	.0534	.0547	.0561	.0574	.0587	.0601	.0615	.0628	.0642	.0656
.07	.0670	.0684	.0698	.0713	.0727	.0741	.0756	.0771	.0786	.0800
.08	.0815	.0830	.0845	.0861	.0876	.0891	.0907	.0922	.0938	.0954
.09	.0969	.0985	.1001	.1017	.1033	.1050	.1066	.1082	.1099	.1115
.10	.1132	.1148	.1165	.1182	.1199	.1216	.1233	.1250	.1267	.1285
.11	.1302	.1319	.1337	.1355	.1372	.1390	.1408	.1426	.1444	.1462
.12	.1480	.1498	.1516	.1534	.1553	.1571	.1590	.1608	.1627	.1646
.13	.1664	.1683	.1702	.1721	.1740	.1759	.1779	.1798	.1817	.1836
.14	.1856	.1875	.1895	.1915	.1934	.1954	.1974	.1994	.2014	.2034
.15	.2054	.2074	.2094	.2115	.2135	.2155	.2176	.2196	.2217	.2238
.16	.2258	.2279	.2300	.2321	.2342	.2363	.2384	.2405	.2426	.2448
.17	.2469	.2490	.2512	.2533	.2555	.2576	.2598	.2620	.2642	.2664
.18	.2685	.2707	.2729	.2751	.2773	.2796	.2818	.2840	.2863	.2885
.19	.2907	.2930	.2953	.2975	.2998	.3021	.3043	.3066	.3089	.3112
.20	.3135	.3158	.3181	.3205	.3228	.3251	.3274	.3298	.3321	.3345
.21	.3368	.3392	.3416	.3439	.3463	.3487	.3511	.3535	.3559	.3583
.22	.3607	.3631	.3655	.3679	.3703	.3728	.3752	.3777	.3801	.3826
.23	.3850	.3875	.3900	.3924	.3949	.3974	.3999	.4024	.4049	.4074
.24	.4099	.4124	.4149	.4174	.4200	.4225	.4250	.4276	.4301	.4327
.25	.4352	.4378	.4404	.4429	.4455	.4481	.4507	.4533	.4559	.4585
.26	.4611	.4637	.4663	.4689	.4715	.4741	.4768	.4794	.4821	.4847
.27	.4874	.4900	.4927	.4953	.4980	.5007	.5034	.5060	.5087	.5114
.28	.5141	.5168	.5195	.5222	.5250	.5277	.5304	.5331	.5359	.5386
.29	.5413	.5441	.5468	.5496	.5524	.5551	.5579	.5607	.5634	.5662
.30	.5690	.5718	.5746	.5774	.5802	.5830	.5858	.5886	.5915	.5943
.31	.5971	.6000	.6028	.6056	.6084	.6113	.6142	.6170	.6199	.6228
.32	.6256	.6285	.6314	.6343	.6372	.6401	.6430	.6459	.6488	.6517
.33	.6546	.6575	.6604	.6633	.6663	.6692	.6721	.6751	.6780	.6810
.34	.6840	.6869	.6899	.6928	.6958	.6988	.7018	.7047	.7077	.7107
.35	.7137	.7167	.7197	.7227	.7257	.7287	.7318	.7348	.7378	.7409
.36	.7439	.7469	.7500	.7530	.7561	.7591	.7622	.7652	.7683	.7714
.37	.7745	.7775	.7806	.7837	.7868	.7899	.7930	.7961	.7992	.8023
.38	.8054	.8085	.8117	.8148	.8179	.8210	.8242	.8273	.8305	.8336
.39	.8368	.8399	.8431	.8463	.8494	.8526	.8558	.8590	.8621	.8653
.40	.8685	.8717	.8749	.8781	.8813	.8845	.8877	.8909	.8942	.8974
.41	.9006	.9038	.9071	.9103	.9136	.9168	.9201	.9233	.9266	.9298
.42	.9331	.9364	.9396	.9429	.9462	.9495	.9528	.9561	.9593	.9626
.43	.9659	.9692	.9725	.9759	.9792	.9825	.9858	.9891	.9925	.9958
.44	.9991	1.0025	1.0058	1.0092	1.0125	1.0159	1.0192	1.0226	1.0259	1.0293
.45	1.0327	1.0361	1.0394	1.0428	1.0462	1.0496	1.0530	1.0564	1.0598	1.0632
.46	1.0666	1.0700	1.0734	1.0768	1.0803	1.0837	1.0871	1.0905	1.0940	1.0974
.47	1.1009	1.1043	1.1077	1.1112	1.1147	1.1181	1.1216	1.1250	1.1285	1.1320
.48	1.1355	1.1389	1.1424	1.1459	1.1494	1.1529	1.1564	1.1599	1.1634	1.1669
.49	1.1704	1.1739	1.1774	1.1809	1.1845	1.1880	1.1915	1.1950	1.1986	1.2021

TABLE 33 (*Continued*)

DISCHARGE IN CUBIC FEET PER SECOND PER FOOT OF LENGTH, OVER SHARP-CRESTED WEIRS, WITHOUT VELOCITY OF APPROACH CORRECTION, BY THE FORMULA

$$Q = 3.34\ H^{1.47}$$

Head in feet	.000	.001	.002	.003	.004	.005	.006	.007	.008	.009
.50	1.2057	1.2092	1.2128	1.2163	1.2199	1.2234	1.2270	1.2306	1.2341	1.2377
.51	1.2413	1.2449	1.2484	1.2520	1.2556	1.2592	1.2628	1.2664	1.2700	1.2736
.52	1.2772	1.2808	1.2845	1.2881	1.2917	1.2953	1.2990	1.3026	1.3062	1.3099
.53	1.3135	1.3171	1.3208	1.3244	1.3281	1.3318	1.3354	1.3391	1.3427	1.3464
.54	1.3501	1.3538	1.3575	1.3611	1.3648	1.3685	1.3722	1.3759	1.3796	1.3833
.55	1.3870	1.3907	1.3944	1.3981	1.4019	1.4056	1.4093	1.4130	1.4168	1.4205
.56	1.4242	1.4280	1.4317	1.4355	1.4392	1.4430	1.4467	1.4505	1.4543	1.4580
.57	1.4618	1.4656	1.4693	1.4731	1.4769	1.4807	1.4844	1.4882	1.4920	1.4958
.58	1.4996	1.5034	1.5072	1.5111	1.5149	1.5187	1.5225	1.5263	1.5301	1.5340
.59	1.5378	1.5416	1.5455	1.5493	1.5531	1.5570	1.5608	1.5647	1.5685	1.5724
.60	1.5763	1.5801	1.5840	1.5879	1.5917	1.5956	1.5995	1.6034	1.6072	1.6111
.61	1.6150	1.6189	1.6228	1.6267	1.6306	1.6345	1.6384	1.6423	1.6463	1.6502
.62	1.6541	1.6580	1.6619	1.6659	1.6698	1.6737	1.6777	1.6816	1.6856	1.6895
.63	1.6935	1.6974	1.7014	1.7053	1.7093	1.7133	1.7172	1.7212	1.7252	1.7292
.64	1.7331	1.7371	1.7411	1.7451	1.7491	1.7531	1.7571	1.7611	1.7651	1.7691
.65	1.7731	1.7771	1.7811	1.7851	1.7891	1.7932	1.7972	1.8012	1.8052	1.8093
.66	1.8133	1.8174	1.8214	1.8255	1.8295	1.8336	1.8376	1.8417	1.8457	1.8498
.67	1.8539	1.8579	1.8620	1.8661	1.8701	1.8742	1.8783	1.8824	1.8865	1.8906
.68	1.8947	1.8988	1.9029	1.9070	1.9111	1.9152	1.9193	1.9234	1.9275	1.9316
.69	1.9358	1.9399	1.9440	1.9482	1.9523	1.9564	1.9606	1.9647	1.9688	1.9730
.70	1.9771	1.9813	1.9855	1.9896	1.9937	1.9979	2.0021	2.0063	2.0104	2.0146
.71	2.0188	2.0230	2.0272	2.0314	2.0356	2.0397	2.0439	2.0481	2.0523	2.0565
.72	2.0607	2.0650	2.0692	2.0734	2.0776	2.0818	2.0860	2.0903	2.0945	2.0987
.73	2.1030	2.1072	2.1114	2.1157	2.1109	2.1242	2.1284	2.1327	2.1369	2.1412
.74	2.1454	2.1497	2.1540	2.1582	2.1625	2.1668	2.1711	2.1753	2.1796	2.1839
.75	2.1882	2.1925	2.1968	2.2011	2.2054	2.2097	2.2140	2.2183	2.2226	2.2269
.76	2.2312	2.2355	2.2399	2.2442	2.2485	2.2528	2.2572	2.2615	2.2658	2.2702
.77	2.2745	2.2788	2.2832	2.2875	2.2919	2.2962	2.3006	2.3050	2.3093	2.3137
.78	2.3181	2.3224	2.3268	2.3312	2.3355	2.3399	2.3443	2.3487	2.3531	2.3575
.79	2.3619	2.3663	2.3707	2.3751	2.3795	2.3839	2.3883	2.3927	2.3971	2.4015
.80	2.4060	2.4104	2.4148	2.4192	2.4237	2.4281	2.4325	2.4370	2.4414	2.4458
.81	2.4503	2.4547	2.4592	2.4636	2.4681	2.4726	2.4770	2.4815	2.4860	2.4904
.82	2.4949	2.4994	2.5038	2.5083	2.5128	2.5173	2.5218	2.5263	2.5308	2.5353
.83	2.5398	2.5443	2.5488	2.5533	2.5578	2.5623	2.5668	2.5713	2.5758	2.5803
.84	2.5849	2.5894	2.5939	2.5985	2.6030	2.6075	2.6121	2.6166	2.6211	2.6257
.85	2.6302	2.6348	2.6393	2.6439	2.6484	2.6530	2.6575	2.6621	2.6666	2.6712
.86	2.6758	2.6804	2.6850	2.6896	2.6941	2.6987	2.7033	2.7079	2.7125	2.7171
.87	2.7217	2.7263	2.7309	2.7355	2.7401	2.7447	2.7493	2.7539	2.7586	2.7632
.88	2.7678	2.7724	2.7771	2.7817	2.7863	2.7910	2.7956	2.8002	2.8049	2.8095
.89	2.8142	2.8188	2.8235	2.8281	2.8328	2.8374	2.8421	2.8468	2.8514	2.8561
.90	2.8608	2.8654	2.8701	2.8748	2.8795	2.8842	2.8888	2.8935	2.8982	2.9029
.91	2.9076	2.9123	2.9170	2.9217	2.9264	2.9311	2.9358	2.9406	2.9453	2.9500
.92	2.9547	2.9594	2.9642	2.9689	2.9736	2.9783	2.9831	2.9878	2.9926	2.9973
.93	3.0020	3.0068	3.0115	3.0163	3.0210	3.0258	3.0306	3.0353	3.0401	3.0448
.94	3.0496	3.0544	3.0591	3.0639	3.0687	3.0735	3.0783	3.0830	3.0878	3.0926
.95	3.0974	3.1022	3.1070	3.1118	3.1166	3.1214	3.1262	3.1310	3.1358	3.1406
.96	3.1455	3.1503	3.1551	3.1599	3.1648	3.1696	3.1744	3.1792	3.1841	3.1889
.97	3.1937	3.1986	3.2034	3.2083	3.2131	3.2180	3.2228	3.2277	3.2325	3.2374
.98	3.2423	3.2471	3.2520	3.2569	3.2617	3.2666	3.2715	3.2764	3.2813	3.2861
.99	3.2910	3.2959	3.3008	3.3057	3.3106	3.3155	3.3204	3.3253	3.3302	3.3351

TABLE 33 (*Continued*)

DISCHARGE IN CUBIC FEET PER SECOND PER FOOT OF LENGTH, OVER SHARP-CRESTED WEIRS, WITHOUT VELOCITY OF APPROACH CORRECTION, BY THE FORMULA

$$Q = 3.34\ H^{1.47}$$

Head in feet	.000	.001	.002	.003	.004	.005	.006	.007	.008	.009
1.00	3.3400	3.3449	3.3498	3.3547	3.3597	3.3646	3.3695	3.3744	3.3793	3.3843
1.01	3.3892	3.3941	3.3991	3.4040	3.4090	3.4139	3.4188	3.4238	3.4287	3.4337
1.02	3.4387	3.4436	3.4486	3.4535	3.4585	3.4635	3.4684	3.4734	3.4784	3.4834
1.03	3.4883	3.4933	3.4983	3.5033	3.5083	3.5132	3.5182	3.5232	3.5282	3.5332
1.04	3.5382	3.5432	3.5482	3.5532	3.5583	3.5633	3.5683	3.5733	3.5783	3.5833
1.05	3.5884	3.5934	3.5984	3.6034	3.6085	3.6135	3.6185	3.6236	3.6286	3.6336
1.06	3.6387	3.6437	3.6488	3.6538	3.6589	3.6640	3.6690	3.6741	3.6791	3.6842
1.07	3.6893	3.6943	3.6994	3.7045	3.7096	3.7146	3.7197	3.7248	3.7299	3.7350
1.08	3.7401	3.7452	3.7503	3.7554	3.7605	3.7656	3.7707	3.7758	3.7809	3.7860
1.09	3.7911	3.7962	3.8013	3.8064	3.8116	3.8167	3.8218	3.8269	3.8321	3.8372
1.10	3.8423	3.8475	3.8526	3.8577	3.8629	3.8680	3.8732	3.8783	3.8835	3.8886
1.11	3.8938	3.8989	3.9041	3.9093	3.9144	3.9196	3.9248	3.9299	3.9351	3.9403
1.12	3.9455	3.9506	3.9558	3.9610	3.9662	3.9714	3.9766	3.9818	3.9870	3.9922
1.13	3.9974	4.0026	4.0078	4.0130	4.0182	4.0234	4.0286	4.0338	4.0390	4.0442
1.14	4.0495	4.0547	4.0599	4.0651	4.0704	4.0756	4.0808	4.0860	4.0913	4.0965
1.15	4.1018	4.1070	4.1123	4.1175	4.1228	4.1280	4.1333	4.1385	4.1438	4.1490
1.16	4.1543	4.1596	4.1649	4.1701	4.1754	4.1807	4.1859	4.1912	4.1965	4.2018
1.17	4.2071	4.2124	4.2176	4.2229	4.2282	4.2335	4.2388	4.2441	4.2494	4.2547
1.18	4.2600	4.2653	4.2706	4.2760	4.2813	4.2866	4.2919	4.2972	4.3025	4.3079
1.19	4.3132	4.3185	4.3238	4.3292	4.3345	4.3399	4.3452	4.3505	4.3559	4.3612
1.20	4.3666	4.3719	4.3773	4.3826	4.3880	4.3934	4.3987	4.4041	4.4094	4.4148
1.21	4.4202	4.4256	4.4309	4.4363	4.4417	4.4471	4.4524	4.4578	4.4632	4.4686
1.22	4.4740	4.4794	4.4848	4.4902	4.4956	4.5010	4.5064	4.5118	4.5172	4.5226
1.23	4.5280	4.5334	4.5388	4.5443	4.5497	4.5551	4.5605	4.5659	4.5714	4.5768
1.24	4.5822	4.5877	4.5931	4.5985	4.6040	4.6094	4.6148	4.6203	4.6257	4.6312
1.25	4.6366	4.6421	4.6476	4.6530	4.6585	4.6639	4.6694	4.6749	4.6803	4.6858
1.26	4.6913	4.6967	4.7022	4.7077	4.7132	4.7187	4.7241	4.7296	4.7351	4.7406
1.27	4.7461	4.7516	4.7571	4.7626	4.7681	4.7736	4.7791	4.7846	4.7901	4.7956
1.28	4.8011	4.8067	4.8122	4.8177	4.8232	4.8287	4.8343	4.8398	4.8453	4.8509
1.29	4.8564	4.8619	4.8675	4.8730	4.8785	4.8841	4.8896	4.8952	4.9007	4.9063
1.30	4.9118	4.9174	4.9229	4.9285	4.9341	4.9396	4.9452	4.9507	4.9563	4.9619
1.31	4.9675	4.9730	4.9786	4.9842	4.9898	4.9954	5.0009	5.0065	5.0121	5.0177
1.32	5.0233	5.0289	5.0345	5.0401	5.0457	5.0513	5.0569	5.0625	5.0681	5.0737
1.33	5.0793	5.0850	5.0906	5.0962	5.1018	5.1074	5.1131	5.1187	5.1243	5.1300
1.34	5.1356	5.1412	5.1468	5.1525	5.1581	5.1638	5.1694	5.1751	5.1807	5.1864
1.35	5.1920	5.1977	5.2033	5.2090	5.2147	5.2203	5.2260	5.2316	5.2373	5.2430
1.36	5.2487	5.2543	5.2600	5.2657	5.2714	5.2770	5.2827	5.2884	5.2941	5.2998
1.37	5.3055	5.3112	5.3169	5.3226	5.3283	5.3340	5.3397	5.3454	5.3511	5.3568
1.38	5.3625	5.3682	5.3739	5.3797	5.3854	5.3911	5.3968	5.4026	5.4083	5.4140
1.39	5.4197	5.4255	5.4312	5.4369	5.4427	5.4484	5.4542	5.4599	5.4656	5.4714
1.40	5.4771	5.4829	5.4886	5.4944	5.5002	5.5059	5.5117	5.5174	5.5232	5.5290
1.41	5.5348	5.5405	5.5463	5.5521	5.5578	5.5636	5.5694	5.5752	5.5810	5.5868
1.42	5.5926	5.5983	5.6041	5.6099	5.6157	5.6215	5.6273	5.6331	5.6389	5.6447
1.43	5.6505	5.6564	5.6622	5.6680	5.6738	5.6796	5.6854	5.6912	5.6971	5.7029
1.44	5.7087	5.7146	5.7204	5.7262	5.7320	5.7379	5.7437	5.7496	5.7554	5.7612
1.45	5.7671	5.7729	5.7788	5.7846	5.7905	5.7963	5.8022	5.8081	5.8139	5.8198
1.46	5.8257	5.8315	5.8374	5.8433	5.8491	5.8550	5.8609	5.8668	5.8727	5.8785
1.47	5.8844	5.8903	5.8962	5.9021	5.9080	5.9139	5.9198	5.9257	5.9316	5.9375
1.48	5.9434	5.9493	5.9552	5.9611	5.9670	5.9729	5.9788	5.9847	5.9906	5.9966
1.49	6.0025	6.0084	6.0143	6.0202	6.0262	6.0321	6.0380	6.0440	6.0499	6.0558

TABLE 33 (*Continued*)

DISCHARGE IN CUBIC FEET PER SECOND PER FOOT OF LENGTH, OVER SHARP-CRESTED WEIRS, WITHOUT VELOCITY OF APPROACH CORRECTION, BY THE FORMULA

$$Q = 3.34\ H^{1.47}$$

Head in feet	.000	.001	.002	.003	.004	.005	.006	.007	.008	.009
1.50	6.0618	6.0677	6.0737	6.0796	6.0856	6.0915	6.0975	6.1034	6.1094	6.1153
1.51	6.1213	6.1272	6.1332	6.1392	6.1451	6.1511	6.1571	6.1630	6.1690	6.1750
1.52	6.1810	6.1869	6.1929	6.1989	6.2049	6.2109	6.2169	6.2229	6.2288	6.2348
1.53	6.2408	6.2468	6.2528	6.2588	6.2648	6.2708	6.2768	6.2829	6.2889	6.2949
1.54	6.3009	6.3069	6.3129	6.3189	6.3250	6.3310	6.3370	6.3430	6.3491	6.3551
1.55	6.3611	6.3672	6.3732	6.3792	6.3853	6.3913	6.3973	6.4034	6.4094	6.4155
1.56	6.4215	6.4276	6.4336	6.4397	6.4458	6.4518	6.4579	6.4639	6.4700	6.4761
1.57	6.4821	6.4882	6.4943	6.5004	6.5064	6.5125	6.5186	6.5247	6.5307	6.5368
1.58	6.5429	6.5490	6.5551	6.5612	6.5673	6.5734	6.5795	6.5856	6.5917	6.5978
1.59	6.6039	6.6100	6.6161	6.6222	6.6283	6.6344	6.6406	6.6467	6.6528	6.6589
1.60	6.6650	6.6712	6.6773	6.6834	6.6895	6.6957	6.7018	6.7079	6.7141	6.7202
1.61	6.7264	6.7325	6.7386	6.7448	6.7509	6.7571	6.7632	6.7694	6.7755	6.7817
1.62	6.7879	6.7940	6.8002	6.8063	6.8125	6.8187	6.8249	6.8310	6.8372	6.8434
1.63	6.8495	6.8557	6.8619	6.8681	6.8743	6.8804	6.8866	6.8928	6.8990	6.9052
1.64	6.9114	6.9176	6.9238	6.9300	6.9362	6.9424	6.9486	6.9548	6.9610	6.9672
1.65	6.9734	6.9797	6.9859	6.9921	6.9983	7.0045	7.0108	7.0170	7.0232	7.0294
1.66	7.0357	7.0419	7.0481	7.0544	7.0606	7.0668	7.0731	7.0793	7.0856	7.0918
1.67	7.0981	7.1043	7.1106	7.1168	7.1231	7.1293	7.1356	7.1418	7.1481	7.1544
1.68	7.1606	7.1669	7.1732	7.1794	7.1857	7.1920	7.1982	7.2045	7.2108	7.2171
1.69	7.2234	7.2297	7.2359	7.2422	7.2485	7.2548	7.2611	7.2674	7.2737	7.2800
1.70	7.2863	7.2926	7.2989	7.3052	7.3115	7.3178	7.3241	7.3304	7.3367	7.3431
1.71	7.3494	7.3557	7.3610	7.3673	7.3737	7.3800	7.3863	7.3926	7.3990	7.4053
1.72	7.4126	7.4190	7.4253	7.4317	7.4380	7.4443	7.4507	7.4570	7.4634	7.4697
1.73	7.4761	7.4824	7.4888	7.4951	7.5015	7.5079	7.5142	7.5206	7.5270	7.5333
1.74	7.5397	7.5461	7.5524	7.5588	7.5652	7.5716	7.5779	7.5843	7.5907	7.5971
1.75	7.6035	7.6099	7.6163	7.6227	7.6290	7.6354	7.6418	7.6482	7.6546	7.6610
1.76	7.6674	7.6738	7.6802	7.6867	7.6931	7.6995	7.7059	7.7123	7.7187	7.7251
1.77	7.7316	7.7380	7.7444	7.7508	7.7573	7.7637	7.7701	7.7765	7.7830	7.7894
1.78	7.7959	7.8023	7.8087	7.8152	7.8216	7.8281	7.8345	7.8410	7.8474	7.8539
1.79	7.8603	7.8668	7.8732	7.8797	7.8862	7.8926	7.8991	7.9056	7.9120	7.9185
1.80	7.9250	7.9314	7.9379	7.9444	7.9509	7.9573	7.9638	7.9703	7.9768	7.9833
1.81	7.9898	7.9963	8.0027	8.0092	8.0157	8.0222	8.0287	8.0352	8.0417	8.0482
1.82	8.0547	8.0612	8.0678	8.0743	8.0808	8.0873	8.0938	8.1003	8.1068	8.1134
1.83	8.1199	8.1264	8.1329	8.1395	8.1460	8.1525	8.1590	8.1656	8.1721	8.1786
1.84	8.1852	8.1917	8.1983	8.2048	8.2114	8.2179	8.2245	8.2310	8.2376	8.2441
1.85	8.2507	8.2572	8.2638	8.2703	8.2769	8.2835	8.2900	8.2966	8.3032	8.3097
1.86	8.3163	8.3229	8.3294	8.3360	8.3426	8.3492	8.3558	8.3623	8.3689	8.3755
1.87	8.3821	8.3887	8.3953	8.4019	8.4085	8.4151	8.4217	8.4283	8.4349	8.4415
1.88	8.4481	8.4547	8.4613	8.4679	8.4745	8.4811	8.4877	8.4944	8.5010	8.5076
1.89	8.5142	8.5208	8.5275	8.5341	8.5407	8.5474	8.5540	8.5606	8.5672	8.5739
1.90	8.5805	8.5872	8.5938	8.6004	8.6071	8.6137	8.6204	8.6270	8.6337	8.6403
1.91	8.6470	8.6537	8.6603	8.6670	8.6736	8.6803	8.6870	8.6936	8.7003	8.7070
1.92	8.7136	8.7203	8.7270	8.7336	8.7403	8.7470	8.7537	8.7604	8.7670	8.7737
1.93	8.7804	8.7871	8.7938	8.8005	8.8072	8.8139	8.8206	8.8273	8.8340	8.8407
1.94	8.8474	8.8541	8.8608	8.8675	8.8742	8.8809	8.8876	8.8943	8.9011	8.9078
1.95	8.9145	8.9212	8.9279	8.9347	8.9414	8.9481	8.9549	8.9616	8.9683	8.9750
1.96	8.9818	8.9885	8.9953	9.0020	9.0087	9.0155	9.0222	9.0290	9.0357	9.0425
1.97	9.0492	9.0560	9.0627	9.0695	9.0762	9.0830	9.0898	9.0965	9.1033	9.1101
1.98	9.1168	9.1236	9.1304	9.1371	9.1439	9.1507	9.1575	9.1643	9.1710	9.1778
1.99	9.1846	9.1914	9.1982	9.2050	9.2118	9.2186	9.2253	9.2321	9.2389	9.2457

TABLE 33 (*Concluded*)

DISCHARGE IN CUBIC FEET PER SECOND PER FOOT OF LENGTH OVER SHARP-CRESTED WEIRS, WITHOUT VELOCITY OF APPROACH CORRECTION, BY THE FORMULA

$$Q = 3.34\ H^{1.47}$$

Head in feet	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
2.0	9.252	9.321	9.389	9.457	9.526	9.595	9.664	9.733	9.802	9.871
2.1	9.940	10.010	10.080	10.150	10.220	10.290	10.361	10.431	10.502	10.573
2.2	10.644	10.715	10.787	10.858	10.930	11.002	11.074	11.146	11.218	11.290
2.3	11.363	11.436	11.506	11.582	11.655	11.728	11.801	11.875	11.949	12.023
2.4	12.096	12.171	12.245	12.319	12.394	12.469	12.543	12.618	12.694	12.769
2.5	12.844	12.920	12.996	13.072	13.148	13.224	13.300	13.377	13.453	13.530
2.6	13.607	13.684	13.761	13.838	13.916	13.993	14.071	14.149	14.227	14.305
2.7	14.383	14.461	14.540	14.619	14.697	14.776	14.855	14.935	15.014	15.093
2.8	15.173	15.253	15.333	15.413	15.493	15.573	15.653	15.734	15.815	15.895
2.9	15.976	16.057	16.138	16.220	16.301	16.383	16.465	16.546	16.628	16.710
3.0	16.793	16.875	16.957	17.040	17.123	17.206	17.289	17.372	17.455	17.538
3.1	17.622	17.705	17.789	17.873	17.957	18.041	18.125	18.210	18.294	18.379
3.2	18.464	18.549	18.634	18.719	18.804	18.889	18.975	19.060	19.146	19.232
3.3	19.318	19.404	19.490	19.577	19.663	19.750	19.837	19.923	20.010	20.097
3.4	20.185	20.272	20.359	20.447	20.535	20.622	20.710	20.798	20.887	20.975
3.5	21.063	21.152	21.240	21.329	21.418	21.507	21.596	21.685	21.775	21.864
3.6	21.954	22.044	22.133	22.223	22.313	22.404	22.494	22.584	22.675	22.765
3.7	22.856	22.947	23.038	23.129	23.210	23.302	23.393	23.484	23.576	23.668
3.8	23.770	23.862	23.954	24.046	24.139	24.231	24.324	24.416	24.509	24.602
3.9	24.695	24.788	24.881	24.975	25.068	25.162	25.256	25.349	25.443	25.537
4.0	25.632	25.726	25.820	25.915	26.009	26.104	26.199	26.294	26.389	26.484
4.1	26.579	26.674	26.769	26.865	26.960	27.056	27.152	27.248	27.344	27.440
4.2	27.537	27.634	27.730	27.827	27.924	28.021	28.118	28.215	28.312	28.409
4.3	28.507	28.604	28.702	28.799	28.897	28.995	29.093	29.191	29.289	29.388
4.4	29.486	29.585	29.684	29.782	29.881	29.980	30.079	30.178	30.278	30.377
4.5	30.477	30.576	30.676	30.776	30.876	30.976	31.076	31.176	31.276	31.377
4.6	31.477	31.578	31.679	31.780	31.881	31.982	32.083	32.184	32.286	32.377
4.7	32.489	32.590	32.692	32.794	32.896	32.998	33.100	33.202	33.305	33.407
4.8	33.510	33.612	33.715	33.818	33.921	34.024	34.127	34.231	34.334	34.438
4.9	34.541	34.645	34.749	34.852	34.956	35.060	35.165	35.269	35.373	35.478
5.0	35.582	35.687	35.792	35.897	36.001	36.107	36.212	36.317	36.422	36.528
5.1	36.633	36.739	36.884	36.950	37.056	37.162	37.268	37.374	37.481	37.587
5.2	37.694	37.800	37.907	38.014	38.121	38.228	38.335	38.442	38.549	38.657
5.3	38.764	38.872	38.980	39.087	39.195	39.303	39.411	39.519	39.628	39.736
5.4	39.844	39.953	40.061	40.170	40.279	40.388	40.497	40.606	40.715	40.824
5.5	40.934	41.043	41.153	41.263	41.372	41.482	41.592	41.702	41.812	41.922
5.6	42.032	42.143	42.253	42.364	42.474	42.585	42.696	42.807	42.918	43.029
5.7	43.140	43.251	43.363	43.474	43.586	43.698	43.809	43.921	44.033	44.145
5.8	44.257	44.369	44.482	44.594	44.707	44.819	44.932	45.045	45.158	45.271
5.9	45.384	45.497	45.610	45.723	45.837	45.950	46.064	46.177	46.291	46.405
6.0	46.519	46.633	46.747	46.861	46.975	47.090	47.204	47.319	47.434	47.548
6.1	47.663	47.778	47.893	48.008	48.123	48.239	48.354	48.469	48.585	48.700
6.2	48.816	48.932	49. 48	49.164	49.280	49.396	49.512	49.628	49.745	49.861
6.3	49.978	50.094	50.211	50.328	50.445	50.562	50.679	50.796	50.913	51.031
6.4	51.148	51.266	51.383	51.501	51.619	51.737	51.855	51.973	52.091	52.209
6.5	52.327	52.446	52.564	52.683	52.801	52.920	53.039	53.158	53.277	53.396
6.6	53.515	53.634	53.754	53.873	53.993	54.112	54.232	54.352	54.471	54.591
6.7	54.711	54.831	54.952	55.072	55.192	55.313	55.433	55.554	55.674	55.795
6.8	55.916	56.037	56.158	56.279	56.400	56.521	56.642	56.764	56.886	57.007
6.9	57.129	57.251	57.372	57.494	57.616	57.738	57.860	57.983	58.105	58.228

Table 34.—Values of $\left(1 + 0.56 \frac{H^2}{d^2}\right)$ **Corresponding to Different Values of** $\frac{H}{d}$ $\left(\text{or } \frac{LH}{A}\right)$. **Velocity of Approach Correction for Sharp-crested Weirs.**

See page 64 for notation

$\frac{H}{d}$	.000	.001	.002	.003	.004	.005	.006	.007	.008	.009
.00	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
.01	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
.02	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
.03	1.001	1.001	1.001	1.001	1.001	1.001	1.001	1.001	1.001	1.001
.04	1.001	1.001	1.001	1.001	1.001	1.001	1.001	1.001	1.001	1.001
.05	1.001	1.001	1.002	1.002	1.002	1.002	1.002	1.002	1.002	1.002
.06	1.002	1.002	1.002	1.002	1.002	1.002	1.002	1.003	1.003	1.003
.07	1.003	1.003	1.003	1.003	1.003	1.003	1.003	1.003	1.003	1.003
.08	1.004	1.004	1.004	1.004	1.004	1.004	1.004	1.004	1.004	1.004
.09	1.005	1.005	1.005	1.005	1.005	1.005	1.005	1.005	1.005	1.005
.10	1.006	1.006	1.006	1.006	1.006	1.006	1.006	1.006	1.007	1.007
.11	1.007	1.007	1.007	1.007	1.007	1.007	1.008	1.008	1.008	1.008
.12	1.008	1.008	1.008	1.008	1.009	1.009	1.009	1.009	1.009	1.009
.13	1.009	1.010	1.010	1.010	1.010	1.010	1.010	1.011	1.011	1.011
.14	1.011	1.011	1.011	1.011	1.012	1.012	1.012	1.012	1.012	1.012
.15	1.013	1.013	1.013	1.013	1.013	1.013	1.014	1.014	1.014	1.014
.16	1.014	1.015	1.015	1.015	1.015	1.015	1.015	1.016	1.016	1.016
.17	1.016	1.016	1.017	1.017	1.017	1.017	1.017	1.018	1.018	1.018
.18	1.018	1.018	1.019	1.019	1.019	1.019	1.019	1.020	1.020	1.020
.19	1.020	1.020	1.021	1.021	1.021	1.021	1.022	1.022	1.022	1.022
.20	1.022	1.023	1.023	1.023	1.023	1.024	1.024	1.024	1.024	1.024
.21	1.025	1.025	1.025	1.025	1.026	1.026	1.026	1.026	1.027	1.027
.22	1.027	1.027	1.028	1.028	1.028	1.028	1.029	1.029	1.029	1.029
.23	1.030	1.030	1.030	1.030	1.031	1.031	1.031	1.031	1.032	1.032
.24	1.032	1.033	1.033	1.033	1.033	1.034	1.034	1.034	1.034	1.035
.25	1.035	1.035	1.036	1.036	1.036	1.036	1.037	1.037	1.037	1.038
.26	1.038	1.038	1.038	1.039	1.039	1.039	1.040	1.040	1.040	1.041
.27	1.041	1.041	1.041	1.042	1.042	1.042	1.043	1.043	1.043	1.044
.28	1.044	1.044	1.045	1.045	1.045	1.045	1.046	1.046	1.046	1.047
.29	1.047	1.047	1.048	1.048	1.048	1.049	1.049	1.049	1.050	1.050
.30	1.050	1.051	1.051	1.051	1.052	1.052	1.052	1.053	1.053	1.053
.31	1.054	1.054	1.055	1.055	1.055	1.056	1.056	1.056	1.057	1.057
.32	1.057	1.058	1.058	1.058	1.059	1.059	1.059	1.060	1.060	1.061
.33	1.061	1.061	1.062	1.062	1.062	1.063	1.063	1.064	1.064	1.064
.34	1.065	1.065	1.065	1.066	1.066	1.067	1.067	1.067	1.068	1.068
.35	1.069	1.069	1.069	1.070	1.070	1.071	1.071	1.071	1.072	1.072
.36	1.073	1.073	1.073	1.074	1.074	1.075	1.075	1.075	1.076	1.076
.37	1.077	1.077	1.077	1.078	1.078	1.079	1.079	1.080	1.080	1.080
.38	1.081	1.081	1.082	1.082	1.083	1.083	1.083	1.084	1.084	1.085
.39	1.085	1.086	1.086	1.086	1.087	1.087	1.088	1.088	1.089	1.089
.40	1.090	1.090	1.090	1.091	1.091	1.092	1.092	1.093	1.093	1.094
.41	1.094	1.095	1.095	1.096	1.096	1.096	1.097	1.097	1.098	1.098
.42	1.099	1.099	1.100	1.100	1.101	1.101	1.102	1.102	1.103	1.103
.43	1.104	1.104	1.104	1.105	1.105	1.106	1.106	1.107	1.107	1.108
.44	1.108	1.109	1.109	1.110	1.110	1.111	1.111	1.112	1.112	1.113
.45	1.113	1.114	1.114	1.115	1.115	1.116	1.116	1.117	1.117	1.118
.46	1.118	1.119	1.120	1.120	1.121	1.121	1.122	1.122	1.123	1.123
.47	1.124	1.124	1.125	1.125	1.126	1.126	1.127	1.127	1.128	1.128
.48	1.129	1.130	1.130	1.131	1.131	1.132	1.132	1.133	1.133	1.134
.49	1.134	1.135	1.136	1.136	1.137	1.137	1.138	1.138	1.139	1.139

Table 35.—Discharge in Cubic Feet per Second per Foot of Length of Sharp-Crested Weirs with End Contractions Suppressed, by the Formula $Q = 3.34\ H^{1.47}\ (1 + .56\ \frac{H^2}{d^2})$

See page 64 for notation

Head in inches	Head in feet	Height of weir in feet							
		0.5	0.75	1.	1.5	2.	3.	4.	6.
2 3/8	.200	.328	.321	.318	.316	.315	.314	.314	.314
2 7/16	.205	.341	.333	.330	.328	.327	.326	.326	.326
2 1/2	.210	.354	.346	.343	.340	.339	.338	.337	.337
2 9/16	.215	.367	.358	.355	.352	.351	.350	.349	.349
2 5/8	.220	.380	.371	.367	.364	.363	.362	.361	.361
2 11/16	.225	.393	.384	.380	.376	.375	.374	.373	.373
2 3/4	.230	.406	.397	.393	.389	.387	.386	.386	.385
2 13/16	.235	.420	.410	.406	.401	.400	.398	.398	.398
2 7/8	.240	.434	.423	.419	.414	.413	.411	.411	.410
2 15/16	.245	.448	.437	.432	.427	.426	.424	.423	.423
3	.250	.462	.450	.445	.440	.438	.436	.436	.436
3 1/16	.255	.477	.464	.458	.453	.451	.449	.449	.449
3 1/8	.260	.491	.478	.472	.466	.464	.462	.462	.462
3 3/16	.265	.506	.492	.486	.480	.478	.476	.475	.475
3 1/4	.270	.521	.506	.500	.494	.491	.489	.488	.488
3 5/16	.275	.536	.521	.514	.507	.505	.502	.502	.501
3 3/8	.280	.551	.535	.528	.521	.518	.516	.515	.515
3 7/16	.285	.567	.550	.542	.535	.532	.529	.529	.528
3 1/2	.290	.582	.565	.557	.549	.546	.543	.543	.542
3 9/16	.295	.598	.580	.571	.563	.560	.557	.557	.556
3 5/8	.300	.614	.595	.586	.578	.574	.572	.571	.570
3 5/8	.305	.630	.610	.601	.592	.589	.586	.585	.584
3 11/16	.310	.646	.625	.616	.607	.603	.600	.599	.598
3 3/4	.315	.662	.641	.631	.622	.618	.614	.613	.612
3 13/16	.320	.679	.657	.646	.636	.632	.629	.628	.626
3 7/8	.325	.696	.673	.662	.651	.647	.643	.642	.641
3 15/16	.330	.713	.689	.677	.666	.662	.658	.657	.655
4	.335	.730	.705	.693	.682	.677	.673	.671	.670
4 1/16	.340	.747	.721	.709	.697	.692	.688	.686	.685
4 1/8	.345	.764	.738	.724	.712	.707	.703	.701	.700
4 3/16	.350	.782	.754	.740	.728	.722	.718	.716	.715
4 1/4	.355	.799	.771	.757	.744	.738	.733	.731	.730
4 5/16	.360	.817	.788	.773	.760	.753	.749	.747	.745
4 3/8	.365	.835	.805	.790	.776	.769	.764	.762	.761
4 7/16	.370	.853	.822	.806	.792	.785	.780	.778	.776
4 1/2	.375	.871	.839	.823	.808	.801	.795	.793	.791
4 9/16	.380	.889	.856	.840	.824	.817	.811	.809	.807
4 5/8	.385	.908	.874	.857	.840	.833	.827	.825	.823
4 11/16	.390	.926	.892	.874	.857	.849	.843	.841	.839
4 3/4	.395	.945	.909	.891	.873	.865	.859	.857	.855
4 13/16	.400	.964	.927	.908	.890	.882	.875	.873	.871
4 7/8	.405	.983	.946	.926	.907	.898	.892	.889	.887
4 15/16	.410	1.003	.964	.943	.924	.915	.908	.905	.903
5	.415	1.022	.982	.961	.941	.932	.925	.921	.919
5 1/16	.420	1.042	1.001	.979	.958	.949	.941	.937	.935

TABLE 35 (*Continued*)

DISCHARGE IN CUBIC FEET PER SECOND PER FOOT OF LENGTH OF SHARP-CRESTED WEIRS WITH END CONTRACTIONS SUPPRESSED, BY THE FORMULA $Q = 3.34\ H^{1.47}\ (1 + .56\ \frac{H^2}{d^2})$

See page 64 for notation

Head in inches	Head in feet	Height of weir in feet							
		0.5	0.75	1.	1.5	2.	3.	4.	6.
5 1/8	.425	1.062	1.019	.997	.975	.966	.958	.954	.952
5 1/8	.430	1.082	1.038	1.015	.993	.983	.975	.971	.968
5 3/16	.435	1.102	1.057	1.033	1.010	1.000	.992	.988	.985
5 1/4	.440	1.122	1.076	1.051	1.028	1.017	1.008	1.005	1.002
5 5/16	.445	1.142	1.095	1.070	1.046	1.035	1.025	1.022	1.018
5 3/8	.450	1.162	1.114	1.088	1.064	1.052	1.042	1.039	1.035
5 7/16	.455	1.183	1.133	1.107	1.082	1.070	1.060	1.056	1.052
5 1/2	.460	1.204	1.153	1.126	1.100	1.088	1.077	1.073	1.070
5 9/16	.465	1.225	1.173	1.145	1.118	1.105	1.095	1.090	1.087
5 5/8	.470	1.246	1.192	1.164	1.136	1.123	1.112	1.107	1.104
5 11/16	.475	1.267	1.212	1.183	1.154	1.141	1.130	1.125	1.121
5 3/4	.480	1.288	1.232	1.202	1.173	1.159	1.147	1.143	1.139
5 13/16	.485	1.309	1.253	1.222	1.192	1.177	1.165	1.160	1.157
5 7/8	.490	1.331	1.273	1.241	1.210	1.196	1.183	1.178	1.174
5 15/16	.495	1.353	1.293	1.261	1.229	1.214	1.201	1.196	1.192
6	.500	1.375	1.314	1.281	1.248	1.233	1.219	1.214	1.210
6 1/16	.505	1.397	1.334	1.301	1.267	1.251	1.238	1.232	1.228
6 1/8	.510	1.419	1.355	1.321	1.286	1.270	1.256	1.250	1.246
6 3/16	.515	1.441	1.376	1.341	1.305	1.289	1.274	1.268	1.264
6 1/4	.520	1.463	1.397	1.361	1.324	1.308	1.293	1.287	1.282
6 5/16	.525	1.485	1.418	1.381	1.344	1.327	1.311	1.305	1.300
6 3/8	.530	1.508	1.440	1.402	1.364	1.346	1.330	1.324	1.318
6 7/16	.535	1.531	1.461	1.422	1.383	1.365	1.349	1.342	1.337
6 1/2	.540	1.554	1.483	1.443	1.403	1.384	1.368	1.361	1.355
6 9/16	.545	1.577	1.504	1.464	1.423	1.404	1.387	1.380	1.374
6 9/16	.550	1.600	1.526	1.485	1.443	1.423	1.406	1.398	1.393
6 5/8	.555	1.624	1.548	1.506	1.463	1.443	1.425	1.417	1.411
6 11/16	.560	1.647	1.570	1.527	1.483	1.462	1.444	1.436	1.430
6 3/4	.565	1.670	1.592	1.548	1.503	1.482	1.463	1.455	1.449
6 13/16	.570	1.694	1.614	1.570	1.524	1.502	1.483	1.475	1.468
6 7/8	.575	1.718	1.637	1.591	1.544	1.522	1.502	1.494	1.487
6 15/16	.580	1.742	1.659	1.613	1.565	1.542	1.522	1.513	1.506
7	.585	1.766	1.682	1.634	1.586	1.562	1.541	1.533	1.525
7 1/16	.590	1.790	1.705	1.656	1.606	1.582	1.561	1.552	1.545
7 1/8	.595	1.814	1.728	1.678	1.627	1.603	1.581	1.572	1.564
7 3/16	.600	1.839	1.751	1.700	1.648	1.623	1.601	1.591	1.584
7 1/4	.605	1.864	1.774	1.723	1.670	1.644	1.621	1.610	1.604
7 5/16	.610	1.888	1.797	1.745	1.691	1.664	1.641	1.630	1.623
7 3/8	.615	1.913	1.821	1.767	1.712	1.685	1.661	1.650	1.643
7 7/16	.620	1.938	1.844	1.790	1.734	1.706	1.681	1.670	1.662
7 1/2	.625	1.963	1.868	1.813	1.755	1.727	1.701	1.690	1.682
7 9/16	.630	1.988	1.891	1.835	1.776	1.748	1.722	1.711	1.702
7 5/8	.635	2.014	1.915	1.858	1.798	1.769	1.742	1.731	1.722
7 11/16	.640	2.039	1.939	1.881	1.820	1.790	1.763	1.751	1.742
7 3/4	.645	2.065	1.963	1.904	1.842	1.811	1.784	1.772	1.762

TABLE 35 (*Continued*)

DISCHARGE IN CUBIC FEET PER SECOND PER FOOT OF LENGTH OF SHARP-CRESTED WEIRS WITH END CONTRACTIONS SUPPRESSED, BY THE FORMULA $Q = 3.34\ H^{1.47}\ (1 + .56\ \frac{H^2}{d^2})$

See page 64 for notation

Head in inches	Head in feet	Height of weir in feet							
		0.5	0.75	1.	1.5	2.	3.	4.	6.
7 13/16	.650	2.090	1.987	1.927	1.864	1.833	1.805	1.792	1.783
7 7/8	.655	2.116	2.011	1.951	1.866	1.854	1.825	1.813	1.803
7 15/16	.660	2.142	2.036	1.974	1.908	1.876	1.846	1.834	1.823
8	.665	2.168	2.060	1.997	1.930	1.897	1.867	1.854	1.844
8 1/16	.670	2.194	2.085	2.021	1.953	1.919	1.888	1.875	1.864
8 1/16	.675	2.220	2.110	2.045	1.975	1.941	1.910	1.896	1.885
8 1/8	.680	2.247	2.135	2.068	1.998	1.963	1.931	1.917	1.905
8 3/16	.685	2.273	2.160	2.092	2.020	1.985	1.952	1.938	1.926
8 1/4	.690	2.300	2.185	2.116	2.043	2.007	2.974	1.959	1.947
8 5/16	.695	2.327	2.210	2.140	2.066	2.029	1.995	1.980	1.968
8 3/8	.700	2.354	2.235	2.165	2.089	2.051	2.017	2.002	1.989
8 7/16	.705	2.381	2.261	2.189	2.112	2.074	2.038	2.023	2.010
8 1/2	.710	2.408	2.286	2.214	2.135	2.096	2.060	2.044	2.031
8 9/16	.715	2.435	2.312	2.238	2.159	2.119	2.082	2.066	2.053
8 5/8	.720	2.463	2.338	2.263	2.182	2.142	2.104	2.087	2.074
8 11/16	.725	2.490	2.364	2.287	2.206	2.164	2.126	2.109	2.095
8 3/4	.730	2.518	2.390	2.312	2.229	2.187	2.148	2.131	2.117
8 13/16	.735	2.545	2.416	2.337	2.253	2.210	2.170	2.153	2.138
8 7/8	.740	2.573	2.442	2.363	2.276	2.233	2.193	2.175	2.160
8 15/16	.745	2.601	2.468	2.388	2.300	2.256	2.215	2.197	2.182
9	.750	2.629	2.494	2.414	2.324	2.279	2.237	2.219	2.203
9 1/16	.755	2.657	2.521	2.439	2.348	2.303	2.260	2.241	2.225
9 1/8	.760	2.686	2.548	2.465	2.372	2.326	2.282	2.263	2.247
9 3/16	.765	2.714	2.574	2.490	2.397	2.349	2.305	2.285	2.269
9 1/4	.770	2.743	2.601	2.516	2.421	2.373	2.327	2.307	2.291
9 5/16	.775	2.771	2.628	2.542	2.446	2.396	2.350	2.330	2.313
9 3/8	.780	2.800	2.655	2.568	2.470	2.420	2.373	2.352	2.335
9 7/16	.785	2.829	2.682	2.593	2.495	2.444	2.396	2.375	2.357
9 1/2	.790	2.858	2.710	2.619	2.519	2.468	2.419	2.398	2.380
9 9/16	.795	2.887	2.737	2.646	2.544	2.493	2.442	2.421	2.402
9 9/16	.800	2.916	2.765	2.672	2.569	2.516	2.465	2.443	2.425
9 5/8	.805	2.946	2.793	2.698	2.594	2.540	2.489	2.466	2.447
9 11/16	.810	2.975	2.820	2.725	2.619	2.565	2.512	2.489	2.470
9 3/4	.815	3.005	2.848	2.751	2.644	2.589	2.536	2.512	2.492
9 13/16	.820	3.034	2.876	2.778	2.669	2.613	2.559	2.535	2.515
9 7/8	.825	3.064	2.904	2.805	2.695	2.637	2.583	2.558	2.538
9 15/16	.830	3.094	2.932	2.832	2.720	2.662	2.607	2.582	2.561
10	.835	3.124	2.961	2.859	2.746	2.687	2.630	2.605	2.584
10 1/16	.840	3.154	2.989	2.887	2.772	2.712	2.654	2.628	2.607
10 1/8	.845	3.184	3.017	2.914	2.797	2.637	2.678	2.652	2.630
10 3/16	.850	3.214	3.045	2.942	2.823	2.762	2.702	2.676	2.653
10 1/4	.855	3.244	3.074	2.969	2.849	2.787	2.726	2.699	2.676
10 5/16	.860	3.275	3.103	2.997	2.875	2.812	2.750	2.723	2.699
10 3/8	.865	3.305	3.132	3.024	2.901	2.837	2.774	2.747	2.723
10 7/16	.870	3.336	3.161	3.052	2.927	2.862	2.799	2.770	2.746

TABLE 35 (*Continued*)

DISCHARGE IN CUBIC FEET PER SECOND PER FOOT OF LENGTH OF SHARP-CRESTED WEIRS WITH END CONTRACTIONS SUPPRESSED, BY THE FORMULA $Q = 3.34\,H^{1.47}\left(1 + .56\,\frac{H^2}{d^2}\right)$

See page 64 for notation

Head in inches	Head in feet	Height of weir in feet							
		0.5	0.75	1.	1.5	2.	3.	4.	6.
10 1/2	.875	3.367	3.190	3.080	2.953	2.887	2.823	2.794	2.770
10 9/16	.880	3.398	3.220	3.108	2.980	2.912	2.848	2.818	2.793
10 5/8	.885	3.429	3.249	3.136	3.006	2.938	2.872	2.842	2.817
10 11/16	.890	3.460	3.278	3.164	3.033	2.963	2.897	2.866	2.841
10 3/4	.895	3.491	3.308	3.192	3.059	2.989	2.921	2.890	2.864
10 13/16	.900	3.523	3.337	3.221	3.086	3.015	2.946	2.915	2.888
10 7/8	.905	3.554	3.367	3.249	3.113	3.040	2.971	2.939	2.912
10 15/16	.910	3.586	3.397	3.478	3.140	3.066	2.996	2.963	2.936
11	.915	3.617	3.427	3.506	3.167	3.092	3.021	2.988	2.960
11 1/16	.920	3.649	3.457	3.535	3.194	3.119	3.046	3.013	2.984
11 1/8	.925	3.681	3.487	3.363	3.221	3.145	3.071	3.037	3.008
11 1/8	.930	3.713	3.517	3.392	3.248	3.171	3.096	3.062	3.032
11 3/16	.935	3.745	3.548	3.421	3.276	3.198	3.122	3.087	3.057
11 1/4	.940	3.777	3.578	3.450	3.303	3.224	3.147	3.111	3.081
11 5/16	.945	3.809	3.609	3.480	3.331	3.251	3.172	3.136	3.105
11 3/8	.950	3.842	3.639	3.509	3.358	3.277	3.198	3.161	3.130
11 7/16	.955	3.874	3.670	3.538	3.386	3.304	3.223	3.186	3.154
11 1/2	.960	3.907	3.701	3.568	3.414	3.331	3.249	3.211	3.179
11 9/16	.965	3.940	3.732	3.597	3.442	3.358	3.275	3.237	3.204
11 5/8	.970	3.972	3.763	3.627	3.470	3.385	3.300	3.262	3.228
11 11/16	.975	4.005	3.793	3.657	3.498	3.412	3.326	3.287	3.253
11 3/4	.980	4.038	3.825	3.687	3.526	3.439	3.352	3.313	3.278
11 13/16	.985	4.071	3.856	3.717	3.554	3.466	3.378	3.338	3.303
11 7/8	.990	4.105	3.887	3.747	3.582	3.493	3.404	3.364	3.328
11 15/16	.995	4.138	3.919	3.777	3.611	3.520	3.431	3.389	3.353
12	1.00	4.171	3.951	3.808	3.639	3.548	3.457	3.415	3.378
12 1/8	1.01	4.238	4.014	3.869	3.697	3.603	3.510	3.466	3.429
12 1/4	1.02	4.306	4.078	3.930	3.754	3.658	3.563	3.518	3.479
12 3/8	1.03	4.374	4.142	3.991	3.812	3.714	3.616	3.570	3.530
12 1/2	1.04	4.442	4.207	4.053	3.871	3.770	3.670	3.623	3.582
12 5/8	1.05	4.511	4.272	4.116	3.929	3.827	3.724	3.675	3.633
12 11/16	1.06	4.580	4.337	4.178	3.988	3.883	3.778	3.728	3.685
12 13/16	1.07	4.649	4.403	4.241	4.048	3.940	3.832	3.781	3.737
12 15/16	1.08	4.719	4.469	4.305	4.108	3.998	3.887	3.835	3.789
13 1/16	1.09	4.789	4.536	4.369	4.168	4.055	3.942	3.889	3.841
13 3/16	1.10	4.859	4.603	4.433	4.228	4.113	3.998	3.943	3.894
13 5/16	1.11	4.930	4.670	4.497	4.288	4.172	4.053	3.997	3.947
13 7/16	1.12	5.002	4.738	4.562	4.349	4.230	4.109	4.051	4.000
13 9/16	1.13	5.073	4.806	4.627	4.411	4.289	4.165	4.106	4.053
13 11/16	1.14	5.145	4.874	4.693	4.473	4.349	4.222	4.161	4.107
13 13/16	1.15	5.218	4.943	4.759	4.535	4.408	4.278	4.216	4.161
13 15/16	1.16	5.291	5.012	4.825	4.597	4.468	4.335	4.272	4.215
14 1/16	1.17	5.364	5.082	4.892	4.660	4.528	4.393	4.328	4.270
14 1/8	1.18	5.437	5.152	4.959	4.723	4.589	4.450	4.384	4.324
14 1/4	1.19	5.511	5.222	5.026	4.786	4.650	4.508	4.440	4.379

TABLE 35 (*Concluded*)

DISCHARGE IN CUBIC FEET PER SECOND PER FOOT OF LENGTH OF SHARP-CRESTED WEIRS WITH END CONTRACTIONS SUPPRESSED, BY THE FORMULA $Q = 3.34\, H^{1.47} \left(1 + .56 \frac{H^2}{d^2}\right)$

See page 64 for notation

Head in inches	Head in feet	Height of weir in feet							
		0.5	0.75	1.	1.5	2.	3.	4.	6.
14 3/8	1.20	5.585	5.293	5.094	4.850	4.711	4.566	4.497	4.435
14 1/2	1.21	5.660	5.364	5.162	4.914	4.772	4.625	4.554	4.490
14 5/8	1.22	5.735	5.435	5.231	4.979	4.834	4.684	4.611	4.546
14 3/4	1.23	5.810	5.506	5.300	5.043	4.896	4.743	4.668	4.602
14 7/8	1.24	5.885	5.578	5.369	5.108	5.959	4.802	4.726	4.658
15	1.25	5.961	5.651	5.438	5.174	5.021	4.861	4.784	4.714
15 1/8	1.26	6.038	5.724	5.508	5.240	5.084	4.921	4.842	4.770
15 1/4	1.27	6.114	5.797	5.578	5.306	5.147	4.981	4.901	4.827
15 3/8	1.28	6.191	5.870	5.648	5.372	5.211	5.042	4.959	4.884
15 1/2	1.29	6.269	5.944	5.719	5.438	5.275	5.102	5.018	4.941
15 5/8	1.30	6.346	6.018	5.791	5.505	5.339	5.163	5.077	4.999
15 11/16	1.31	6.424	6.092	5.862	5.573	5.403	5.224	5.137	5.057
15 13/16	1.32	6.503	6.167	5.934	5.640	5.468	5.286	5.197	5.115
15 15/16	1.33	6.582	6.242	6.006	5.708	5.533	5.348	5.257	5.173
16 1/16	1.34	6.661	6.318	6.079	5.776	5.599	5.410	5.317	5.231
16 3/16	1.35	6.740	6.394	6.152	5.845	5.664	5.472	5.377	5.290
16 5/16	1.36	6.820	6.470	6.225	5.914	5.730	5.535	5.438	5.349
16 7/16	1.37	6.900	6.546	6.298	5.983	5.796	5.598	5.499	5.408
16 9/16	1.38	6.981	6.623	6.372	6.052	5.863	5.661	5.560	5.468
16 11/16	1.39	7.061	6.700	6.446	6.122	5.930	5.724	5.622	5.527
16 13/16	1.40	7.142	6.778	6.521	6.192	5.997	5.788	5.684	5.587
16 15/16	1.41	7.224	6.856	6.596	6.262	6.065	5.852	5.746	5.647
17 1/16	1.42	7.306	6.934	6.671	6.333	6.133	5.916	5.808	5.707
17 1/8	1.43	7.388	7.012	6.746	6.404	6.201	5.980	5.870	5.768
17 1/4	1.44	7.470	7.091	6.822	6.475	6.268	6.045	5.933	5.829
17 3/8	1.45	7.553	7.170	6.898	6.547	6.337	6.110	5.996	5.890
17 1/2	1.46	7.636	7.249	6.975	6.619	6.406	6.175	6.059	5.951
17 5/8	1.47	7.719	7.329	7.052	6.692	6.476	6.241	6.122	6.012
17 3/4	1.48	7.803	7.409	7.129	6.764	6.545	6.307	6.186	6.074
17 7/8	1.49	7.887	7.490	7.206	6.837	6.615	6.373	6.250	6.136
18	1.50	7.971	7.571	7.284	6.910	6.685	6.439	6.314	6.198
18 1/8	1.51	8.056	7.652	7.362	6.984	6.756	6.506	6.379	6.260
18 1/4	1.52	8.141	7.733	7.440	7.058	6.826	6.573	6.443	6.322
18 3/8	1.53	8.226	7.815	7.519	7.132	6.897	6.640	6.508	6.385
18 1/2	1.54	8.312	7.897	7.598	7.206	6.969	6.707	6.573	6.448
18 5/8	1.55	8.398	7.979	7.677	7.281	7.040	6.775	6.639	6.511
18 11/16	1.56	8.484	8.062	7.757	7.356	7.112	6.843	6.705	6.575
18 13/16	1.57	8.570	8.145	7.837	7.431	7.185	6.911	6.771	6.638
18 15/16	1.58	8.657	8.228	7.917	7.507	7.257	6.979	6.837	6.702
19 1/16	1.59	8.744	8.311	7.998	7.583	7.330	7.048	6.903	6.766
19 3/16	1.60	8.832	8.395	8.079	7.659	7.402	7.117	6.970	6.830
19 5/16	1.61	8.919	8.479	8.160	7.736	7.476	7.186	7.037	6.895
19 7/16	1.62	9.007	8.564	8.241	7.813	7.549	7.255	7.104	6.960
19 9/16	1.63	9.096	8.649	8.323	7.890	7.623	7.325	7.171	7.025
19 11/16	1.64	9.185	8.734	8.405	7.967	7.697	7.395	7.239	7.090

TABLE 36.—VALUES OF THE EXPRESSION $\left(1+\frac{1}{5}\sqrt{\frac{DH}{Zd_1}}\right)\left(1+1.2\frac{D}{Z}\right)$ CORRESPONDING TO DIFFERENT VALUES OF $\frac{H}{d_1}$ AND $\frac{D}{Z}$ TO ASSIST IN SOLUTION OF SUBMERGED-WEIR FORMULA (FORMULA (41)), Page 82.

See pages 64 and 65 for notation

$\frac{D}{Z}$	$\frac{H}{d_1}$						$\frac{D}{Z}$	$\frac{H}{d_1}$					
	0.0	0.1	0.2	0.3	0.4	0.5		0.0	0.1	0.2	0.3	0.4	0.5
0.0	1.00	1.00	1.00	1.00	1.00	1.00	5.0	7.00	7.99	8.40	8.71	8.98	9.21
0.1	1.12	1.14	1.15	1.16	1.16	1.17	5.1	7.12	8.14	8.56	8.88	9.16	9.39
0.2	1.24	1.27	1.29	1.30	1.31	1.32	5.2	7.24	8.28	8.72	9.05	9.33	9.58
0.3	1.36	1.41	1.43	1.44	1.45	1.47	5.3	7.36	8.43	8.88	9.22	9.50	9.76
0.4	1.48	1.54	1.56	1.58	1.60	1.61	5.4	7.48	8.58	9.04	9.38	9.68	9.94
0.5	1.60	1.67	1.70	1.72	1.74	1.76	5.5	7.60	8.73	9.20	9.55	9.85	10.12
0.6	1.72	1.80	1.84	1.87	1.89	1.91	5.6	7.72	8.88	9.36	9.72	10.03	10.30
0.7	1.84	1.94	1.98	2.01	2.03	2.06	5.7	7.84	9.02	9.52	9.89	10.21	10.49
0.8	1.96	2.07	2.12	2.15	2.18	2.21	5.8	7.96	9.17	9.68	10.06	10.39	10.67
0.9	2.08	2.21	2.26	2.30	2.33	2.36	5.9	8.08	9.32	9.84	10.23	10.56	10.86
1.0	2.20	2.34	2.40	2.44	2.48	2.51	6.0	8.20	9.47	10.00	10.40	10.74	11.04
1.1	2.32	2.47	2.54	2.59	2.63	2.66	6.1	8.32	9.62	10.16	10.57	10.92	11.23
1.2	2.44	2.61	2.68	2.73	2.78	2.82	6.2	8.44	9.77	10.32	10.74	11.10	11.41
1.3	2.56	2.74	2.82	2.88	2.93	2.97	6.3	8.56	9.92	10.48	10.91	11.28	11.60
1.4	2.68	2.88	2.96	3.03	3.08	3.13	6.4	8.68	10.07	10.64	11.08	11.46	11.79
1.5	2.8	3.02	3.11	3.18	3.23	3.28	6.5	8.80	10.22	10.81	11.25	11.64	11.97
1.6	2.92	3.15	3.25	3.33	3.39	3.44	6.6	8.92	10.37	10.97	11.42	11.82	12.16
1.7	3.04	3.29	3.40	3.48	3.54	3.60	6.7	9.04	10.52	11.13	11.59	12.00	12.35
1.8	3.16	3.43	3.54	3.63	3.70	3.76	6.8	9.16	10.67	11.30	11.76	12.18	12.54
1.9	3.28	3.57	3.69	3.78	3.85	3.92	6.9	9.28	10.82	11.46	11.93	12.36	12.73
2.0	3.40	3.70	3.83	3.93	4.01	4.08	7.0	9.40	10.97	11.62	12.11	12.55	12.92
2.1	3.52	3.84	3.98	4.08	4.17	4.24	7.1	9.52	11.12	11.79	12.28	12.73	13.11
2.2	3.64	3.98	4.12	4.23	4.32	4.40	7.2	9.64	11.28	11.96	12.46	12.91	13.30
2.3	3.76	4.12	4.27	4.38	4.48	4.57	7.3	9.76	11.43	12.12	12.64	13.10	13.49
2.4	3.88	4.26	4.42	4.54	4.64	4.73	7.4	9.88	11.58	12.29	12.82	13.28	13.68
2.5	4.00	4.40	4.57	4.69	4.80	4.89	7.5	10.00	11.73	12.45	13.00	13.46	13.87
2.6	4.12	4.54	4.71	4.85	4.96	5.06	7.6	10.12	11.88	12.62	13.17	13.65	14.07
2.7	4.24	4.68	4.86	5.00	5.12	5.23	7.7	10.24	12.04	12.78	13.35	13.83	14.26
2.8	4.36	4.82	5.01	5.15	5.28	5.39	7.8	10.36	12.19	12.95	13.53	14.02	14.45
2.9	4.48	4.96	5.16	5.31	5.45	5.56	7.9	10.48	12.34	13.12	13.71	14.21	14.65
3.0	4.60	5.10	5.31	5.47	5.61	5.73	8.0	10.60	12.50	13.28	13.88	14.39	14.84
3.1	4.72	5.25	5.46	5.63	5.77	5.90	8.1	10.72	12.65	13.45	14.06	14.58	15.04
3.2	4.84	5.39	5.61	5.79	5.94	6.06	8.2	10.84	12.80	13.62	14.24	14.77	15.24
3.3	4.96	5.53	5.77	5.95	6.10	6.23	8.3	10.96	12.96	13.78	14.42	14.96	15.43
3.4	5.08	5.67	5.92	6.11	6.26	6.40	8.4	11.08	13.11	13.95	14.60	15.14	15.63
3.5	5.20	5.82	6.07	6.27	6.43	6.58	8.5	11.20	13.26	14.12	14.78	15.33	15.83
3.6	5.32	5.96	6.22	6.43	6.60	6.75	8.6	11.32	13.42	14.29	14.96	15.52	16.02
3.7	5.44	6.10	6.38	6.59	6.76	6.92	8.7	11.44	13.57	14.46	15.14	15.71	16.22
3.8	5.56	6.25	6.53	6.75	6.93	7.09	8.8	11.56	13.73	14.63	15.32	15.90	16.42
3.9	5.68	6.39	6.68	6.91	7.10	7.27	8.9	11.68	13.88	14.80	15.50	16.09	16.61
4.0	5.80	6.53	6.84	7.07	7.27	7.44	9.0	11.80	14.04	14.97	15.68	16.28	16.81
4.1	5.92	6.68	6.99	7.23	7.44	7.62	9.1	11.92	14.19	15.14	15.86	16.47	17.01
4.2	6.04	6.82	7.15	7.40	7.61	7.79	9.2	12.04	14.35	15.31	16.04	16.66	17.21
4.3	6.16	6.97	7.30	7.56	7.78	7.97	9.3	12.16	14.51	15.48	16.23	16.85	17.41
4.4	6.28	7.11	7.46	7.72	7.95	8.14	9.4	12.28	14.66	15.65	16.41	17.04	17.61
4.5	6.40	7.26	7.61	7.89	8.12	8.32	9.5	12.40	14.82	15.82	16.59	17.23	17.81
4.6	6.52	7.40	7.77	8.05	8.29	8.50	9.6	12.52	14.97	15.99	16.77	17.43	18.01
4.7	6.64	7.55	7.93	8.22	8.46	8.68	9.7	12.64	15.13	16.16	16.95	17.62	18.21
4.8	6.76	7.70	8.08	8.38	8.63	8.86	9.8	12.76	15.29	16.33	17.14	17.82	18.41
4.9	6.88	7.84	8.24	8.55	8.81	9.03	9.9	12.88	15.44	16.51	17.32	18.01	18.61

Table 37.—Discharge in Cubic Feet per Second Over Right-angled *V*-notch Weirs by the Formula,

$$Q = 2.52\ H^{2.47}$$

Head *H* in feet	.000	.001	.002	.003	.004	.005	.006	.007	.008	.009
.10	.0085	.0088	.0090	.0092	.0094	.0096	.0099	.0101	.0103	.0106
.11	.0108	.0111	.0113	.0116	.0118	.0121	.0123	.0126	.0129	.0131
.12	.0134	.0137	.0140	.0142	.0145	.0148	.0151	.0154	.0157	.0160
.13	.0163	.0166	.0170	.0173	.0176	.0179	.0183	.0186	.0189	.0193
.14	.0196	.0200	.0203	.0207	.0210	.0214	.0218	.0221	.0225	.0229
.15	.0233	.0236	.0240	.0244	.0248	.0252	.0256	.0260	.0264	.0268
.16	.0273	.0277	.0281	.0285	.0290	.0294	.0299	.0303	.0308	.0312
.17	.0317	.0321	.0326	.0331	.0335	.0340	.0345	.0350	.0355	.0360
18	.0365	.0370	.0375	.0380	.0385	.0390	.0396	.0401	.0406	.0411
19	.0417	.0422	.0428	.0434	.0439	.0445	.0450	.0456	.0462	.0468
.20	.0473	.0479	.0485	.0491	.0497	.0503	.0509	.0515	.0522	.0528
.21	.0534	.0540	.0547	.0553	.0559	.0566	.0572	.0579	.0586	.0592
.22	.0599	.0606	.0612	.0619	.0626	.0633	.0640	.0647	.0654	.0661
.23	.0668	.0676	.0683	.0690	.0697	.0705	.0712	.0720	.0727	.0735
.24	.0742	.0750	.0758	.0765	.0773	.0781	.0789	.0797	.0805	.0813
.25	.0821	.0829	.0837	.0845	.0854	.0862	.0870	.0879	.0887	.0896
.26	.0904	.0913	.0922	.0930	.0939	.0948	.0957	.0966	.0975	.0984
.27	.0993	.1002	.1011	.1020	.1029	.1039	.1048	.1057	.1067	.1076
.28	.1086	.1096	.1105	.1115	.1125	.1135	.1145	.1155	.1165	.1175
.29	.1185	.1195	.1205	.1215	.1225	.1236	.1246	.1256	.1267	.1277
.30	.129	.130	.131	.132	.133	.134	.135	.136	.138	.139
.31	.140	.141	.142	.143	.144	.145	.147	.148	.149	.150
.32	.151	.152	.154	.155	.156	.157	.158	.159	.161	.162
.33	.163	.164	.166	.167	.168	169	.171	.172	.173	.174
.34	.176	.177	.178	.179	.181	.182	.183	.185	.186	.187
.35	.189	.190	.191	.193	.194	.195	.197	.198	.199	.201
.36	.202	.204	.205	.206	.208	.209	.211	.212	.213	.215
.37	.216	.218	.219	.221	.222	.224	.225	.227	.228	.229
.38	.231	.232	.234	.236	.237	.239	.240	.242	.243	.245
.39	.246	.248	.249	.251	.253	.254	.256	.257	.259	.261
.40	.262	.264	.265	.267	.269	.270	.272	.274	.275	.277
.41	.279	.280	.282	.284	.285	.287	.289	.291	.292	.294
.42	.296	.297	.299	.301	.303	.305	.306	.308	.310	.312
.43	.313	.315	.317	.319	.321	.323	.324	.326	.328	.330
.44	.332	.334	.335	.337	.339	.341	.343	.345	.347	.349
.45	.351	.353	.354	.356	.358	.360	.362	.364	.366	.368
.46	.370	.372	.374	.376	.378	.380	.382	.384	.386	.388
.47	.390	.393	.395	.397	.399	.401	.403	.405	.407	.409
.48	.411	.413	.416	.418	.420	.422	.424	.426	.428	.431
.49	.433	.435	.437	.439	.442	.444	.446	.448	.450	.453
.50	.455	.457	.459	.462	.464	.466	.468	.471	.473	.475
.51	.478	.480	.482	.485	.487	.489	.492	.494	.496	.499
.52	.501	.504	.506	.508	.511	.513	.516	.518	.520	.523
.53	.525	.528	.530	.533	.535	.538	.540	.543	.545	.548
.54	.550	.553	.555	.558	.560	.563	.565	.568	.571	.573
.55	.576	.578	.581	.583	.586	.589	.591	.594	.597	.599
.56	.602	.605	.607	.610	.613	.615	.618	.621	.623	.626
.57	.629	.632	.634	.637	.640	.643	.645	.648	.651	.654
.58	.656	.659	.662	.665	.668	.670	.673	.676	.679	.682
.59	.685	.688	.690	.693	.696	.699	.702	.705	.708	.711

TABLE 37 (*Continued*)

DISCHARGE IN CUBIC FEET PER SECOND OVER RIGHT-ANGLED *V*-NOTCH WEIRS BY THE FORMULA, $Q = 2.52 H^{2.47}$

Head *H* in feet	.000	.001	.002	.003	.004	.005	.006	.007	.008	.009
.60	.714	.717	.720	.723	.725	.728	.731	.734	.737	.740
.61	.743	.746	.749	.753	.756	.759	.762	.765	.768	.771
.62	.774	.777	.780	.783	.786	.789	.793	.796	.799	.802
.63	.805	.808	.811	.815	.818	.821	.824	.827	.831	.834
.64	.837	.840	.843	.847	.850	.853	.857	.860	.863	.866
.65	.870	.873	.876	.880	.883	.886	.890	.893	.896	.900
.66	.903	.906	.910	.913	.917	.920	.923	.927	.930	.934
.67	.937	.941	.944	.948	.951	.955	.958	.962	.965	.969
.68	.972	.976	.979	.983	.986	.990	.994	.997	1.001	1.004
.69	1.008	1.011	1.015	1.019	1.022	1.026	1.030	1.033	1.037	1.040
.70	1.044	1.048	1.052	1.055	1.059	1.063	1.067	1.070	1.074	1.078
.71	1.082	1.085	1.089	1.093	1.097	1.101	1.104	1.108	1.112	1.116
.72	1.120	1.123	1.127	1.131	1.135	1.139	1.143	1.147	1.151	1.154
.73	1.158	1.162	1.166	1.170	1.174	1.178	1.182	1.186	1.190	1.194
.74	1.198	1.202	1.206	1.210	1.214	1.218	1.222	1.226	1.230	1.234
.75	1.238	1.242	1.246	1.251	1.255	1.259	1.263	1.267	1.271	1.275
.76	1.279	1.284	1.288	1.292	1.296	1.300	1.305	1.309	1.313	1.317
.77	1.321	1.326	1.330	1.334	1.339	1.343	1.347	1.351	1.356	1.360
.78	1.364	1.369	1.373	1.377	1.382	1.386	1.390	1.395	1.399	1.403
.79	1.408	1.412	1.417	1.421	1.426	1.430	1.434	1.439	1.443	1.448
.80	1.452	1.457	1.461	1.466	1.470	1.475	1.479	1.484	1.488	1.493
.81	1.498	1.502	1.507	1.511	1.516	1.521	1.525	1.530	1.534	1.539
.82	1.544	1.548	1.553	1.558	1.562	1.567	1.572	1.576	1.581	1.586
.83	1.591	1.595	1.600	1.605	1.610	1.614	1.619	1.624	1.629	1.633
.84	1.638	1.643	1.648	1.653	1.658	1.662	1.667	1.672	1.677	1.682
.85	1.687	1.692	1.697	1.702	1.707	1.712	1.717	1.721	1.726	1.731
.86	1.736	1.741	1.746	1.751	1.756	1.761	1.766	1.772	1.777	1.782
.87	1.787	1.792	1.797	1.802	1.807	1.812	1.817	1.822	1.828	1.833
.88	1.838	1.843	1.848	1.853	1.859	1.864	1.869	1.874	1.879	1.885
.89	1.890	1.895	1.900	1.906	1.911	1.916	1.921	1.927	1.932	1.937
.90	1.943	1.948	1.953	1.959	1.964	1.969	1.975	1.980	1.986	1.991
.91	1.996	2.002	2.007	2.013	2.018	2.024	2.029	2.035	2.040	2.046
.92	2.051	2.057	2.062	2.068	2.073	2.079	2.084	2.090	2.095	2.101
.93	2.107	2.112	2.118	2.123	2.129	2.135	2.140	2.146	2.152	2.157
.94	2.163	2.169	2.174	2.180	2.186	2.191	2.197	2.203	2.209	2.214
.95	2.220	2.226	2.232	2.238	2.243	2.249	2.255	2.261	2.267	2.272
.96	2.278	2.284	2.290	2.296	2.302	2.308	2.314	2.320	2.326	2.332
.97	2.337	2.343	2.349	2.355	2.361	2.367	2.373	2.379	2.385	2.391
.98	2.397	2.403	2.410	2.416	2.422	2.428	2.434	2.440	2.446	2.452
.99	2.458	2.464	2.471	2.477	2.483	2.489	2.495	2.501	2.507	2.513
1.00	2.520	2.526	2.533	2.539	2.545	2.551	2.558	2.564	2.570	2.576
1.01	2.583	2.589	2.595	2.602	2.608	2.614	2.621	2.627	2.634	2.640
1.02	2.646	2.653	2.659	2.666	2.672	2.679	2.685	2.691	2.698	2.704
1.03	2.711	2.718	2.724	2.731	2.737	2.744	2.750	2.757	2.763	2.770
1.04	2.776	2.783	2.790	2.796	2.803	2.810	2.816	2.823	2.830	2.836
1.05	2.843	2.850	2.856	2.863	2.870	2.876	2.883	2.890	2.897	2.903
1.06	2.910	2.917	2.924	2.931	2.937	2.944	2.951	2.958	2.965	2.972
1.07	2.978	2.985	2.992	2.999	3.006	3.013	3.020	3.027	3.034	3.041
1.08	3.048	3.055	3.062	3.069	3.076	3.083	3.090	3.097	3.104	3.111
1.09	3.118	3.125	3.132	3.139	3.146	3.153	3.160	3.168	3.175	3.182

TABLE 37 (*Concluded*)

DISCHARGE IN CUBIC FEET PER SECOND OVER RIGHT-ANGLED *V*-NOTCH WEIRS BY THE FORMULA, $Q = 2.52\ H^{2.47}$

Head *H* in feet	.000	.001	.002	.003	.004	.005	.006	.007	.008	.009
1.10	3.189	3.196	3.203	3.211	3.218	3.225	3.232	3.239	3.247	3.254
1.11	3.261	3.268	3.276	3.283	3.290	3.298	3.305	3.312	3.319	3.327
1.12	3.334	3.341	3.349	3.356	3.364	3.371	3.378	3.386	3.393	3.401
1.13	3.408	3.416	3.423	3.431	3.438	3.446	3.453	3.461	3.468	3.476
1.14	3.483	3.491	3.498	3.506	3.513	3.521	3.529	3.536	3.544	3.551
1.15	3.559	3.567	3.574	3.582	3.590	3.597	3.605	3.613	3.621	3.628
1.16	3.636	3.644	3.652	3.659	3.667	3.675	3.683	3.690	3.698	3.706
1.17	3.714	3.722	3.730	3.737	3.745	3.753	3.761	3.769	3.777	3.785
1.18	3.793	3.801	3.809	3.817	3.825	3.833	3.841	3.849	3.857	3.865
1.19	3.873	3.881	3.889	3.897	3.905	3.913	3.921	3.929	3.937	3.945
1.20	3.954	3.962	3.970	3.978	3.986	3.994	4.003	4.011	4.019	4.027
1.21	4.035	4.044	4.052	4.060	4.069	4.077	4.085	4.093	4.102	4.110
1.22	4.118	4.127	4.135	4.143	4.152	4.160	4.169	4.177	4.185	4.194
1.23	4.202	4.211	4.219	4.228	4.236	4.245	4.253	4.262	4.270	4.279
1.24	4.287	4.296	4.304	4.313	4.321	4.330	4.339	4.347	4.356	4.364
1.25	4.373	4.382	4.390	4.399	4.408	4.416	4.425	4.434	4.442	4.451
1.26	4.460	4.469	4.477	4.486	4.495	4.504	4.513	4.521	4.530	4.539
1.27	4.548	4.557	4.566	4.574	4.583	4.592	4.601	4.610	4.619	4.628
1.28	4.637	4.646	4.655	4.664	4.673	4.682	4.691	4.700	4.709	4.718
1.29	4.727	4.736	4.745	4.754	4.763	4.772	4.781	4.790	4.800	4.809
1.30	4.818	4.827	4.836	4.845	4.855	4.864	4.873	4.882	4.891	4.901
1.31	4.910	4.919	4.928	4.938	4.947	4.956	4.966	4.975	4.984	4.994
1.32	5.003	5.012	5.022	5.031	5.041	5.050	5.059	5.069	5.078	5.088
1.33	5.097	5.107	5.116	5.126	5.135	5.145	5.154	5.164	5.173	5.183
1.34	5.192	5.202	5.211	5.221	5.231	5.240	5.250	5.260	5.269	5.279
1.35	5.288	5.298	5.308	5.318	5.327	5.337	5.347	5.357	5.366	5.376
1.36	5.386	5.396	5.405	5.415	5.425	5.435	5.445	5.455	5.464	5.474
1.37	5.484	5.494	5.504	5.514	5.524	5.534	5.544	5.554	5.564	5.574
1.38	5.584	5.594	5.604	5.614	5.624	5.634	5.644	5.654	5.664	5.674
1.39	5.684	5.694	5.704	5.714	5.724	5.734	5.745	5.755	5.765	5.775
1.40	5.785	5.796	5.806	5.816	5.826	5.837	5.847	5.857	5.867	5.878
1.41	5.888	5.898	5.909	5.919	5.929	5.940	5.950	5.961	5.971	5.981
1.42	5.992	6.002	6.013	6.023	6.034	6.044	6.055	6.065	6.076	6.086
1.43	6.097	6.107	6.118	6.128	6.139	6.149	6.160	6.171	6.181	6.192
1.44	6.202	6.213	6.224	6.234	6.245	6.256	6.266	6.277	6.288	6.299
1.45	6.309	6.320	6.331	6.342	6.352	6.363	6.374	6.385	6.396	6.407
1.46	6.417	6.428	6.439	6.450	6.461	6.472	6.483	6.495	6.504	6.515
1.47	6.526	6.537	6.548	6.559	6.570	6.581	6.593	6.604	6.615	6.626
1.48	6.637	6.648	6.659	6.670	6.681	6.692	6.703	6.715	6.726	6.737
1.49	6.748	6.759	6.770	6.782	6.793	6.804	6.815	6.827	6.838	6.849
1.50	6.860	6.872	6.883	6.894	6.906	6.917	6.928	6.940	6.951	6.962
1.51	6.974	6.985	6.997	7.008	7.020	7.031	7.043	7.054	7.065	7.077
1.52	7.088	7.100	7.112	7.123	7.135	7.146	7.158	7.169	7.181	7.193
1.53	7.204	7.216	7.228	7.239	7.251	7.263	7.274	7.286	7.298	7.309
1.54	7.321	7.333	7.345	7.356	7.368	7.380	7.392	7.404	7.415	7.427
1.55	7.439	7.451	7.463	7.475	7.487	7.499	7.510	7.522	7.534	7.546
1.56	7.558	7.570	7.582	7.594	7.606	7.618	7.630	7.642	7.654	7.666
1.57	7.678	7.691	7.703	7.715	7.727	7.739	7.751	7.763	7.775	7.788
1.58	7.800	7.812	7.824	7.836	7.849	7.861	7.873	7.885	7.898	7.910
1.59	7.922	7.935	7.947	7.959	7.972	7.984	7.996	8.009	8.021	8.034

TABLE 38.—DISCHARGE OVER CIPPOLETTI WEIRS IN CUBIC FEET PER SECOND BY THE FORMULA $Q = 3.3\frac{3}{8} LH^{3/2}$

Head in feet	Length of weir in feet									
	1.0	1.5	2.0	2.5	3.0	4.0	5.0	6.0	7.0	8.0
.01	.003	.01	.01	.01	.01	.01	.02	.02	.02	.03
.02	.010	.01	.02	.02	.03	.04	.05	.06	.07	.08
.03	.018	.03	.04	.04	.05	.07	.09	.11	.12	.14
.04	.027	.04	.05	.07	.08	.11	.13	.16	.19	.22
.05	.038	.06	.08	.09	.11	.15	.19	.23	.26	.30
.06	.050	.07	.10	.12	.15	.20	.25	.30	.35	.40
.07	.062	.09	.12	.15	.19	.25	.31	.37	.44	.50
.08	.076	.11	.15	.19	.23	.30	.38	.46	.53	.61
.09	.091	.14	.18	.23	.27	.36	.45	.55	.64	.73
.10	.107	.16	.21	.27	.32	.43	.53	.64	.75	.85
.11	.123	.18	.25	.31	.37	.49	.61	.74	.86	.98
.12	.140	.21	.28	.35	.42	.56	.70	.84	.98	1.12
.13	.158	.24	.32	.39	.47	.63	.79	.95	1.10	1.26
.14	.176	.26	.35	.43	.53	.71	.88	1.06	1.23	1.41
.15	.196	.29	.39	.49	.59	.78	.98	1.17	1.37	1.56
.16	.216	.32	.43	.54	.65	.86	1.08	1.29	1.51	1.72
.17	.236	.35	.47	.59	.71	.94	1.18	1.42	1.65	1.89
.18	.257	.39	.51	.64	.77	1.03	1.29	1.54	1.80	2.06
.19	.279	.42	.56	.70	.84	1.12	1.39	1.67	1.95	2.23
.20	.301	.45	.60	.75	.90	1.20	1.51	1.81	2.11	2.41
.21	.324	.49	.65	.81	.97	1.30	1.62	1.94	2.27	2.59
.22	.347	.52	.69	.87	1.04	1.39	1.74	2.08	2.43	2.78
.23	.371	.56	.74	.93	1.11	1.49	1.86	2.23	2.60	2.97
.24	.396	.59	.79	.99	1.19	1.58	1.98	2.38	2.77	3.17
.25	.421	.63	.84	1.05	1.26	1.68	2.10	2.53	2.95	3.37
.26	.446	.67	.89	1.11	1.34	1.79	2.23	2.68	3.12	3.57
.27	.472	.71	.94	1.18	1.42	1.89	2.36	2.83	3.31	3.78
.28	.499	.75	1.00	1.25	1.50	2.00	2.49	2.99	3.49	3.99
.29	.526	.79	1.05	1.31	1.58	2.10	2.63	3.15	3.68	4.21
.30	.553	.83	1.11	1.38	1.66	2.21	2.77	3.32	3.87	4.43
.31	.581	.87	1.16	1.45	1.74	2.32	2.91	3.49	4.07	4.65
.32	.609	.91	1.22	1.52	1.83	2.44	3.05	3.66	4.27	4.88
.33	.638	.96	1.28	1.59	1.91	2.55	3.19	3.83	4.47	5.11
.34	.667	1.00	1.33	1.67	2.00	2.67	3.34	4.00	4.67	5.34
.35	.697	1.05	1.39	1.74	2.09	2.79	3.49	4.18	4.88	5.58
.36	.727	1.09	1.45	1.82	2.18	2.91	3.64	4.36	5.09	5.82
.37	.758	1.14	1.52	1.89	2.27	3.03	3.79	4.55	5.30	6.06
.38	.789	1.18	1.58	1.97	2.37	3.15	3.94	4.73	5.52	6.31
.39	.820	1.23	1.64	2.05	2.46	3.28	4.10	4.92	5.74	6.56
.40	.852	1.28	1.70	2.13	2.56	3.41	4.26	5.11	5.96	6.81
.41	.884	1.33	1.77	2.21	2.65	3.54	4.42	5.30	6.19	7.07
.42	.916	1.37	1.83	2.29	2.75	3.67	4.58	5.50	6.41	7.33
.43	.949	1.42	1.90	2.37	2.85	3.80	4.75	5.70	6.65	7.59
.44	.983	1.47	1.97	2.46	2.95	3.93	4.91	5.90	6.88	7.86
.45	1.016	1.52	2.03	2.54	3.05	4.07	5.08	6.10	7.11	8.13
.46	1.050	1.58	2.10	2.62	3.15	4.20	5.25	6.30	7.35	8.40
.47	1.085	1.63	2.17	2.71	3.25	4.34	5.42	6.51	7.59	8.68
.48	1.120	1.68	2.24	2.80	3.36	4.48	5.60	6.72	7.84	8.96
.49	1.155	1.73	2.31	2.89	3.46	4.62	5.77	6.93	8.08	9.24
.50	1.190	1.79	2.38	2.97	3.57	4.76	5.95	7.14	8.33	9.52

TABLE 38 (*Continued*)

DISCHARGE OVER CIPPOLETTI WEIRS IN CUBIC FEET PER SECOND BY THE FORMULA $Q = 3.3\frac{2}{3} LH^{3/2}$

Head in feet	Length of weir in feet									
	1.0	1.5	2.0	2.5	3.0	4.0	5.0	6.0	7.0	8.0
.51	1.226	1.84	2.45	3.06	3.68	4.90	6.13	7.36	8.58	9.81
.52	1.262	1.89	2.52	3.15	3.79	5.05	6.31	7.57	8.84	10.10
.53	1.299	1.95	2.60	3.25	3.90	5.20	6.50	7.79	9.09	10.39
.54	1.336	2.00	2.67	3.34	4.01	5.34	6.68	8.02	9.35	10.69
.55	1.373	2.06	2.75	3.43	4.12	5.49	6.87	8.24	9.61	10.99
.56	1.411	2.12	2.82	3.53	4.23	5.64	7.05	8.47	9.88	11.29
.57	1.449	2.17	2.90	3.62	4.35	5.80	7.24	8.69	10.14	11.59
.58	1.487	2.23	2.97	3.72	4.46	5.95	7.44	8.92	10.41	11.90
.59	1.526	2.29	3.05	3.81	4.58	6.10	7.63	9.15	10.68	12.21
.60	1.565	2.35	3.13	3.91	4.69	6.26	7.82	9.39	10.95	12.52
.61	1.604	2.41	3.21	4.01	4.81	6.42	8.02	9.62	11.23	12.83
.62	1.644	2.47	3.29	4.11	4.93	6.57	8.22	9.86	11.51	13.15
.63	1.683	2.53	3.37	4.21	5.05	6.73	8.42	10.10	11.78	13.47
.64	1.724	2.59	3.45	4.31	5.17	6.89	8.62	10.34	12.07	13.79
.65	1.764	2.65	3.53	4.41	5.29	7.06	8.82	10.59	12.35	14.11
.66	1.805	2.71	3.61	4.51	5.42	7.22	9.03	10.83	12.64	14.44
.67	1.846	2.77	3.69	4.61	5.54	7.39	9.23	11.08	12.92	14.77
.68	1.888	2.83	3.78	4.72	5.66	7.55	9.44	11.33	13.21	15.10
.69	1.930	2.89	3.86	4.82	5.79	7.72	9.65	11.58	13.51	15.44
.70	1.972	2.96	3.94	4.93	5.92	7.89	9.86	11.83	13.80	15.77
.71	2.014	3.02	4.03	5.03	6.04	8.06	10.07	12.08	14.10	16.11
.72	2.057	3.09	4.11	5.14	6.17	8.23	10.28	12.34	14.40	16.45
.73	2.100	3.15	4.20	5.25	6.30	8.40	10.50	12.60	14.70	16.80
.74	2.143	3.21	4.29	5.36	6.43	8.57	10.72	12.86	15.00	17.15
.75	2.187	3.28	4.37	5.47	6.56	8.75	10.93	13.12	15.31	17.49
.76	2.231	3.34	4.46	5.58	6.69	8.92	11.15	13.38	15.61	17.84
.77	2.275	3.41	4.55	5.69	6.82	9.10	11.37	13.65	15.92	18.20
.78	2.319	3.48	4.64	5.80	6.96	9.28	11.60	13.92	16.23	18.55
.79	2.364	3.56	4.73	5.91	7.09	9.46	11.82	14.18	16.55	18.91
.80	2.409	3.61	4.82	6.02	7.23	9.64	12.05	14.45	16.86	19.27
.81	2.454	3.68	4.91	6.13	7.36	9.82	12.27	14.73	17.18	19.63
.82	2.500	3.75	5.00	6.25	7.50	10.00	12.50	15.00	17.50	20.00
.83	2.546	3.82	5.09	6.36	7.64	10.18	12.73	15.27	17.82	20.37
.84	2.592	3.89	5.18	6.48	7.78	10.37	12.96	15.55	18.14	20.74
.85	2.638	3.96	5.28	6.59	7.92	10.55	13.19	15.83	18.47	21.11
.86	2.685	4.03	5.37	6.71	8.06	10.74	13.43	16.11	18.80	21.48
.87	2.732	4.10	5.46	6.83	8.20	10.93	13.66	16.39	19.12	21.86
.88	2.779	4.17	5.56	6.95	8.34	11.12	13.90	16.68	19.45	22.23
.89	2.827	4.24	5.65	7.07	8.48	11.31	14.13	16.96	19.79	22.61
.90	2.875	4.31	5.75	7.19	8.62	11.50	14.37	17.25	20.12	23.00
.91	2.923	4.38	5.85	7.31	8.77	11.69	14.61	17.54	20.46	23.38
.92	2.971	4.46	5.94	7.43	8.91	11.88	14.85	17.83	20.80	23.77
.93	3.019	4.53	6.04	7.55	9.06	12.08	15.10	18.12	21.14	24.16
.94	3.068	4.60	6.14	7.67	9.20	12.27	15.34	18.41	21.48	24.55
.95	3.117	4.68	6.23	7.79	9.35	12.47	15.59	18.70	21.82	24.94
.96	3.167	4.75	6.33	7.92	9.50	12.67	15.83	19.00	22.17	25.33
.97	3.216	4.82	6.43	8.04	9.65	12.87	16.08	19.30	22.51	25.73
.98	3.266	4.90	6.53	8.16	9.80	13.06	16.33	19.60	22.86	26.13
.99	3.316	4.97	6.63	8.29	9.95	13.27	16.58	19.90	23.21	26.53
1.00	3.367	5.05	6.73	8.42	10.10	13.47	16.83	20.20	23.57	26.93

TABLE 38 (*Continued*)

DISCHARGE OVER CIPPOLETTI WEIRS IN CUBIC FEET PER SECOND BY THE FORMULA, $Q = 3.3\frac{2}{3} LH^{3/2}$

Head in feet.	Length of weir in feet									
	1.0	1.5	2.0	2.5	3.0	4.0	5.0	6.0	7.0	8.0
1.01	3.417	5.13	6.83	8.54	10.25	13.67	17.09	20.50	23.92	27.34
1.02	3.468	5.20	6.94	8.67	10.40	13.87	17.34	20.81	24.28	27.75
1.03	3.519	5.28	7.04	8.80	10.56	14.08	17.60	21.12	24.64	28.15
1.04	3.571	5.36	7.14	8.93	10.71	14.28	17.85	21.42	24.99	28.57
1.05	3.622	5.43	7.24	9.06	10.87	14.49	18.11	21.73	25.36	28.98
1.06	3.674	5.51	7.35	9.19	11.02	14.70	18.37	22.05	25.72	29.39
1.07	3.726	5.59	7.45	9.32	11.18	14.91	18.63	22.36	26.08	29.81
1.08	3.779	5.67	7.56	9.45	11.34	15.11	18.89	22.67	26.45	30.23
1.09	3.831	5.75	7.66	9.58	11.49	15.32	19.16	22.99	26.82	30.65
1.10	3.884	5.83	7.77	9.71	11.65	15.54	19.42	23.30	27.19	31.07
1.11	3.937	5.91	7.87	9.84	11.81	15.75	19.69	23.62	27.56	31.50
1.12	3.990	5.99	7.98	9.98	11.97	15.96	19.95	23.94	27.93	31.92
1.13	4.044	6.07	8.09	10.11	12.13	16.18	20.22	24.26	28.31	32.35
1.14	4.098	6.15	8.20	10.24	12.29	16.39	20.49	24.59	28.69	32.78
1.15	4.152	6.23	8.30	10.38	12.46	16.61	20.76	24.91	29.06	33.22
1.16	4.206	6.31	8.41	10.51	12.62	16.82	21.03	25.24	29.44	33.65
1.17	4.261	6.39	8.52	10.65	12.78	17.04	21.30	25.56	29.82	34.09
1.18	4.315	6.47	8.63	10.79	12.95	17.26	21.58	25.89	30.21	34.52
1.19	4.370	6.55	8.74	10.92	13.11	17.48	21.85	26.22	30.59	34.96
1.20	4.426	6.64	8.85	11.06	13.28	17.70	22.13	26.55	30.98	35.40
1.21	4.481	6.72	8.96	11.20	13.44	17.92	22.40	26.89	31.37	35.85
1.22	4.537	6.80	9.07	11.34	13.61	18.15	22.68	27.22	31.76	36.29
1.23	4.593	6.89	9.19	11.48	13.78	18.37	22.96	27.56	32.15	36.74
1.24	4.649	6.97	9.30	11.62	13.95	18.59	23.24	27.89	32.54	37.19
1.25	4.705	7.06	9.41	11.76	14.12	18.82	23.53	28.23	32.94	37.64
1.26	4.762	7.14	9.52	11.90	14.28	19.05	23.81	28.57	33.33	38.09
1.27	4.818	7.23	9.64	12.04	14.46	19.27	24.09	28.91	33.73	38.55
1.28	4.875	7.31	9.75	12.19	14.63	19.50	24.38	29.25	34.13	39.00
1.29	4.933	7.40	9.87	12.33	14.80	19.73	24.66	29.60	34.53	39.46
1.30	4.990	7.48	9.98	12.47	14.97	19.96	24.95	29.94	34.93	39.92
1.31	5.048	7.57	10.10	12.62	15.14	20.19	25.24	30.29	35.34	40.38
1.32	5.106	7.66	10.21	12.76	15.32	20.42	25.53	30.63	35.74	40.85
1.33	5.164	7.75	10.33	12.91	15.49	20.66	25.82	30.98	36.15	41.31
1.34	5.222	7.83	10.44	13.05	15.67	20.89	26.11	31.33	36.56	41.78
1.35	5.281	7.92	10.56	13.20	15.84	21.12	26.40	31.68	36.97	42.25
1.36	5.340	8.01	10.68	13.35	16.02	21.26	26.70	32.04	37.38	42.72
1.37	5.399	8.10	10.80	13.50	16.20	21.59	26.99	32.39	37.79	43.19
1.38	5.458	8.19	10.92	13.64	16.37	21.83	27.29	32.75	38.20	43.66
1.39	5.517	8.27	11.03	13.79	16.55	22.07	27.59	33.10	38.62	44.14
1.40	5.577	8.36	11.15	13.94	16.73	22.31	27.88	33.46	39.04	44.62
1.41	5.637	8.45	11.27	14.09	16.91	22.55	28.18	33.82	39.46	45.09
1.42	5.697	8.54	11.39	14.24	17.09	22.79	28.48	34.18	39.88	45.57
1.43	5.757	8.63	11.51	14.39	17.27	23.03	28.79	34.54	40.30	46.06
1.44	5.818	8.73	11.64	14.54	17.45	23.27	29.09	34.91	40.72	46.54
1.45	5.878	8.82	11.76	14.69	17.63	23.51	29.39	35.27	41.15	47.03
1.46	5.939	8.91	11.88	14.85	17.82	23.76	29.70	35.64	41.57	47.51
1.47	6.000	9.00	12.00	15.00	18.00	24.00	30.00	36.00	42.00	48.00
1.48	6.062	9.09	12.12	15.15	18.19	24.25	30.31	36.37	42.43	48.49
1.49	6.123	9.18	12.25	15.31	18.37	24.49	30.62	36.74	42.86	48.99
1.50	6.185	9.28	12.37	15.46	18.56	24.74	30.92	37.11	43.30	49.48

Table 38 (*Concluded*)

Discharge Over Cippoletti Weirs in Cubic Feet per Second by the Formula $Q = 3.3\frac{2}{3} LH^{3/2}$

Head in feet	Length of weir in feet									
	1.0	1.5	2.0	2.5	3.0	4.0	5.0	6.0	7.0	8.0
1.51	6.247	9.37	12.49	15.62	18.74	24.99	31.23	37.48	43.73	49.98
1.52	6.309	9.46	12.62	15.77	18.93	25.24	31.55	37.85	44.16	50.47
1.53	6.371	9.56	12.74	15.93	19.11	25.49	31.86	38.23	44.60	50.97
1.54	6.434	9.65	12.87	16.08	19.30	25.74	32.17	38.60	45.04	51.47
1.55	6.497	9.75	12.99	16.24	19.49	25.99	32.48	38.98	45.48	51.97
1.56	6.560	9.84	13.12	16.40	19.68	26.24	32.80	39.36	45.92	52.48
1.57	6.623	9.93	13.25	16.56	19.87	26.49	33.11	39.74	46.36	52.98
1.58	6.686	10.03	13.37	16.71	20.06	26.75	33.43	40.12	46.80	53.49
1.59	6.750	10.12	13.50	16.87	20.25	27.00	33.73	40.50	47.25	54.00
1.60	6.814	10.22	13.63	17.03	20.44	27.25	34.07	40.88	47.70	54.51
1.61	6.878	10.32	13.76	17.19	20.63	27.51	34.39	41.27	48.14	55.02
1.62	6.942	10.41	13.88	17.35	20.83	27.77	34.71	41.65	48.59	55.53
1.63	7.006	10.51	14.01	17.51	21.02	28.02	35.03	42.04	49.04	56.05
1.64	7.071	10.61	14.14	17.68	21.21	28.28	35.35	42.42	49.50	56.57
1.65	7.136	10.71	14.27	17.84	21.41	28.54	35.68	42.81	49.95	57.08
1.66	7.200	10.80	14.40	18.00	21.60	28.80	36.00	43.20	50.40	57.60
1.67	7.266	10.90	14.53	18.16	21.80	29.06	36.33	43.59	50.86	58.13
1.68	7.331	11.00	14.66	18.33	21.99	29.32	36.66	43.99	51.32	58.65
1.69	7.397	11.10	14.79	18.49	22.19	29.59	36.98	44.38	51.78	59.17
1.70	7.462	11.19	14.92	18.65	22.39	29.85	37.31	44.77	52.24	59.70
1.71	7.528	11.29	15.06	18.82	22.58	30.11	37.64	45.17	52.70	60.23
1.72	7.594	11.39	15.19	18.98	22.78	30.38	37.97	45.57	53.16	60.76
1.73	7.661	11.49	15.32	19.15	22.98	30.64	38.30	45.96	53.62	61.29
1.74	7.727	11.59	15.45	19.32	23.18	30.91	38.64	46.36	54.09	61.82
1.75	7.794	11.69	15.59	19.48	23.38	31.18	38.97	46.76	54.56	62.35
1.76	7.861	11.79	15.72	19.65	23.58	31.44	39.30	47.16	55.03	62.89
1.77	7.928	11.89	15.86	19.82	23.78	31.71	39.64	47.57	55.50	63.42
1.78	7.995	11.99	15.99	19.99	23.99	31.98	39.98	47.97	55.97	63.96
1.79	8.063	12.09	16.13	20.16	24.19	32.25	40.31	48.38	56.44	64.50
1.80	8.130	12.20	16.26	20.32	24.39	32.52	40.65	48.78	56.91	65.04
1.81	8.198	12.30	16.40	20.49	24.59	32.79	40.99	49.19	57.39	65.59
1.82	8.266	12.40	16.53	20.66	24.80	33.06	41.33	49.60	57.86	66.13
1.83	8.334	12.50	16.67	20.83	25.00	33.34	41.67	50.01	58.34	66.68
1.84	8.403	12.61	16.81	21.01	25.21	33.61	42.01	50.42	58.82	67.22
1.85	8.471	12.71	16.94	21.18	25.41	33.89	42.36	50.83	59.30	67.77
1.86	8.540	12.81	17.08	21.35	25.62	34.16	42.70	51.24	59.78	68.32
1.87	8.609	12.91	17.22	21.52	25.83	34.44	43.05	51.66	60.26	68.87
1.88	8.678	13.02	17.36	21.69	26.03	34.71	43.39	52.07	60.75	69.43
1.89	8.748	13.12	17.50	21.87	26.24	34.99	43.74	52.49	61.23	69.98
1.90	8.817	13.22	17.63	22.04	26.45	35.27	44.09	52.90	61.72	70.54
1.91	8.887	13.33	17.77	22.22	26.66	35.55	44.43	53.32	62.21	71.10
1.92	8.957	13.43	17.91	22.39	26.87	35.83	44.78	53.74	62.70	71.65
1.93	9.027	13.54	18.05	22.57	27.08	36.11	45.13	54.16	63.19	72.21
1.94	9.097	13.64	18.19	22.74	27.29	36.39	45.49	54.58	63.68	72.78
1.95	9.168	13.75	18.34	22.92	27.50	36.67	45.84	55.00	64.17	73.34
1.96	9.238	13.86	18.48	23.10	27.71	36.95	46.19	55.43	64.67	73.90
1.97	9.309	13.96	18.62	23.27	27.93	37.24	46.54	55.85	65.16	74.47
1.98	9.380	14.07	18.76	23.45	28.14	37.52	46.90	56.28	65.66	75.04
1.99	9.451	14.18	18.90	23.63	28.35	37.80	47.26	56.71	66.16	75.61
2.00	9.522	14.28	19.04	23.80	28.57	38.09	47.61	57.13	66.66	76.18

TABLE 39.—DISCHARGE IN CUBIC FEET PER SECOND PER FOOT OF LENGTH OVER SHARP-CRESTED WEIRS, WITHOUT VELOCITY OF APPROACH CORRECTION, BY THE FRANCIS FORMULA $Q = 3.33H^{3/2}$

Head in feet	.000	.001	.002	.003	.004	.005	.006	.007	.008	.009
.00	.0000	.0001	.0003	.0005	.0008	.0012	.0015	.0020	.0024	.0028
.01	.0033	.0038	.0044	.0049	.0055	.0061	.0067	.0074	.0080	.0087
.02	.0094	.0101	.0109	.0116	.0124	.0132	.0140	.0148	.0156	.0164
.03	.0173	.0182	.0191	.0200	.0209	.0218	.0227	.0237	.0247	.0256
.04	.0266	.0276	.0287	.0297	.0307	.0318	.0329	.0339	.0350	.0361
.05	.0372	.0384	.0395	.0406	.0418	.0430	.0441	.0453	.0465	.0477
.06	.0489	.0502	.0514	.0527	.0539	.0552	.0565	.0578	.0590	.0604
.07	.0617	.0630	.0643	.0657	.0670	.0684	.0698	.0712	.0725	.0739
.08	.0753	.0768	.0782	.0796	.0811	.0825	.0840	.0855	.0869	.0884
.09	.0899	.0914	.0929	.0944	.0960	.0975	.0990	.1006	.1022	.1037
.10	.1053	.1069	.1085	.1101	.1117	.1133	.1149	.1166	.1182	.1198
.11	.1215	.1231	.1248	.1265	.1282	.1299	.1316	.1333	.1350	.1367
.12	.1384	.1402	.1419	.1436	.1454	.1472	.1489	.1507	.1525	.1543
.13	.1561	.1579	.1597	.1615	.1633	.1652	.1670	.1689	.1707	.1726
.14	.1744	.1763	.1782	.1801	.1820	.1839	.1858	.1877	.1896	.1915
.15	.1935	.1954	.1973	.1993	.2012	.2032	.2052	.2072	.2091	.2111
.16	.2131	.2151	.2171	.2191	.2212	.2232	.2252	.2273	.2293	.2314
.17	.2334	.2355	.2375	.2396	.2417	.2438	.2459	.2480	.2501	.2522
.18	.2543	.2564	.2586	.2607	.2628	.2650	.2671	.2693	.2714	.2736
.19	.2758	.2780	.2802	.2823	.2845	.2867	.2890	.2912	.2934	.2956
.20	.2978	.3001	.3023	.3046	.3068	.3091	.3113	.3136	.3159	.3182
.21	.3205	.3228	.3250	.3274	.3297	.3320	.3343	.3366	.3389	.3413
.22	.3436	.3460	.3483	.3507	.3530	.3554	.3578	.3601	.3625	.3649
.23	.3673	.3697	.3721	.3745	.3769	.3794	.3818	.3842	.3866	.3891
.24	.3915	.3940	.3964	.3989	.4014	.4038	.4063	.4088	.4113	.4138
.25	.4162	.4187	.4213	.4238	.4263	.4288	.4313	.4339	.4364	.4389
.26	.4415	.4440	.4466	.4491	.4517	.4543	.4568	.4594	.4620	.4646
.27	.4672	.4698	.4724	.4750	.4776	.4802	.4828	.4855	.4881	.4907
.28	.4934	.4960	.4987	.5013	.5040	.5067	.5093	.5120	.5147	.5174
.29	.5200	.5227	.5254	.5281	.5308	.5336	.5363	.5390	.5417	.5444
.30	.5472	.5499	.5527	.5554	.5582	.5609	.5637	.5664	.5692	.5720
.31	.5748	.5775	.5803	.5831	.5859	.5887	.5915	.5943	.5972	.6000
.32	.6028	.6056	.6085	.6113	.6141	.6170	.6198	.6227	.6255	.6284
.33	.6313	.6341	.6370	.6399	.6428	.6457	.6486	.6515	.6544	.6573
.34	.6602	.6631	.6660	.6689	.6719	.6748	.6777	.6807	.6836	.6866
.35	.6895	.6925	.6954	.6984	.7014	.7043	.7073	.7103	.7133	.7163
.36	.7193	.7223	.7253	.7283	.7313	.7343	.7373	.7404	.7434	.7464
.37	.7495	.7525	.7555	.7586	.7616	.7647	.7678	.7708	.7739	.7770
.38	.7800	.7831	.7862	.7893	.7924	.7955	.7986	.8017	.8048	.8079
.39	.8110	.8142	.8173	.8204	.8235	.8267	.8298	.8330	.8361	.8393
.40	.8424	.8456	.8488	.8519	.8551	.8583	.8615	.8646	.8678	.8710
.41	.8742	.8774	.8806	.8838	.8870	.8903	.8935	.8967	.8999	.9032
.42	.9064	.9096	.9129	.9161	.9194	.9226	.9259	.9292	.9324	.9357
.43	.9390	.9422	.9455	.9488	.9521	.9554	.9587	.9620	.9653	.9686
.44	.9719	.9752	.9785	.9819	.9852	.9885	.9919	.9952	.9985	1.0019
.45	1.0052	1.0086	1.0119	1.0153	1.0187	1.0220	1.0254	1.0288	1.0321	1.0355
.46	1.0389	1.0423	1.0457	1.0491	1.0525	1.0559	1.0593	1.0627	1.0661	1.0696
.47	1.0730	1.0764	1.0798	1.0833	1.0867	1.0901	1.0936	1.0970	1.1005	1.1039
.48	1.1074	1.1109	1.1143	1.1178	1.1213	1.1248	1.1282	1.1317	1.1352	1.1387
.49	1.1422	1.1457	1.1492	1.1527	1.1562	1.1597	1.1632	1.1668	1.1703	1.1738

Table 39 (*Continued*)

Discharge in Cubic Feet per Second per Foot of Length over Sharp-Crested Weirs, without Velocity of Approach Correction, by the Francis Formula $Q = 3.33H^{3/2}$

Head in feet	.000	.001	.002	.003	.004	.005	.006	.007	.008	.009
.50	1.1773	1.1809	1.1844	1.1879	1.1915	1.1950	1.1986	1.2021	1.2057	1.2093
.51	1.2128	1.2164	1.2200	1.2235	1.2271	1.2307	1.2343	1.2379	1.2415	1.2451
.52	1.2487	1.2523	1.2559	1.2595	1.2631	1.2667	1.2703	1.2740	1.2776	1.2812
.53	1.2849	1.2885	1.2921	1.2958	1.2994	1.3031	1.3067	1.3104	1.3141	1.3177
.54	1.3214	1.3251	1.3287	1.3324	1.3361	1.3398	1.3435	1.3472	1.3509	1.3546
.55	1.3583	1.3620	1.3657	1.3694	1.3731	1.3768	1.3806	1.3843	1.3880	1.3918
.56	1.3955	1.3992	1.4030	1.4067	1.4105	1.4142	1.4180	1.4217	1.4255	1.4293
.57	1.4330	1.4368	1.4406	1.4444	1.4481	1.4519	1.4557	1.4595	1.4633	1.4671
.58	1.4709	1.4747	1.4785	1.4823	1.4862	1.4900	1.4938	1.4976	1.5014	1.5053
.59	1.5091	1.5130	1.5168	1.5206	1.5245	1.5283	1.5322	1.5361	1.5399	1.5438
.60	1.5476	1.5515	1.5554	1.5593	1.5631	1.5670	1.5709	1.5748	1.5787	1.5826
.61	1.5865	1.5904	1.5943	1.5982	1.6021	1.6060	1.6100	1.6139	1.6178	1.6217
.62	1.6257	1.6296	1.6335	1.6375	1.6414	1.6454	1.6493	1.6533	1.6572	1.6612
.63	1.6652	1.6691	1.6731	1.6771	1.6810	1.6850	1.6890	1.6930	1.6970	1.7010
.64	1.7050	1.7090	1.7130	1.7170	1.7210	1.7250	1.7290	1.7330	1.7370	1.7410
.65	1.7451	1.7491	1.7531	1.7572	1.7612	1.7652	1.7693	1.7733	1.7774	1.7814
.66	1.7855	1.7896	1.7936	1.7977	1.8018	1.8058	1.8099	1.8140	1.8181	1.8221
.67	1.8262	1.8303	1.8344	1.8385	1.8426	1.8467	1.8508	1.8549	1.8590	1.8632
.68	1.8673	1.8714	1.8755	1.8796	1.8838	1.8879	1.8920	1.8962	1.9003	1.9045
.69	1.9086	1.9128	1.9169	1.9211	1.9252	1.9294	1.9336	1.9377	1.9419	1.9461
.70	1.9503	1.9544	1.9586	1.9628	2.9670	1.9712	1.9754	1.9796	1.9838	1.9880
.71	1.9922	1.9964	2.0006	2.0048	2.0091	2.0133	2.0175	2.0217	2.0260	2.0302
.72	2.0344	2.0387	2.0429	2.0472	2.0514	2.0557	2.0599	2.0642	2.0684	2.0727
.73	2.0770	2.0812	2.0855	2.0898	2.0941	2.0983	2.1026	2.1069	2.1112	2.1155
.74	2.1198	2.1241	2.1284	2.1327	2.1370	2.1413	2.1456	2.1499	2.1543	2.1586
.75	2.1629	2.1672	2.1716	2.1759	2.1802	2.1846	2.1889	2.1932	2.1976	2.2019
.76	2.2063	2.2107	2.2150	2.2194	2.2237	2.2281	2.2325	2.2369	2.2412	2.2456
.77	2.2500	2.2544	2.2588	2.2632	2.2675	2.2719	2.2763	2.2807	2.2851	2.2896
.78	2.2940	2.2984	2.3028	2.3072	2.3116	2.3161	2.3205	2.3249	2.3293	2.3338
.79	2.3382	2.3427	2.3471	2.3515	2.3560	2.3604	2.3649	2.3694	2.3738	2.3783
.80	2.3828	2.3872	2.3917	2.3962	2.4006	2.4051	2.4096	2.4141	2.4186	2.4231
.81	2.4276	2.4321	2.4366	2.4411	2.4456	2.4501	2.4546	2.4591	2.4636	2.4681
.82	2.4727	2.4772	2.4817	2.4862	2.4908	2.4953	2.4999	2.5044	2.5089	2.5135
.83	2.5180	2.5226	2.5271	2.5317	2.5363	2.5408	2.5454	2.5500	2.5545	2.5591
.84	2.5637	2.5683	2.5728	2.5774	2.5820	2.5866	2.5912	2.5958	2.6004	2.6050
.85	2.6096	2.6142	2.6188	2.6234	2.6280	2.6327	2.6373	2.6419	2.6465	2.6511
.86	2.6558	2.6604	2.6650	2.6697	2.6743	2.6790	2.6836	2.6883	2.6929	2.6976
.87	2.7022	2.7069	2.7116	2.7162	2.7209	2.7256	2.7302	2.7349	2.7396	2.7443
.88	2.7490	2.7536	2.7583	2.7630	2.7677	2.7724	2.7771	2.7818	2.7865	2.7912
.89	2.7959	2.8007	2.8054	2.8101	2.8148	2.8195	2.8243	2.8290	2.8337	2.8385
.90	2.8432	2.8479	2.8527	2.8574	2.8622	2.8669	2.8717	2.8764	2.8812	2.8860
.91	2.8907	2.8955	2.9003	2.9050	2.9098	2.9146	2.9194	2.9241	2.9289	2.9337
.92	2.9385	2.9433	2.9481	2.9529	2.9577	2.9625	2.9673	2.9721	2.9769	2.9817
.93	2.9865	2.9914	2.9962	3.0010	3.0058	3.0107	3.0155	3.0203	3.0252	3.0300
.94	3.0348	3.0397	3.0445	3.0494	3.0542	3.0591	3.0639	3.0688	3.0737	3.0785
.95	3.0834	3.0883	3.0931	3.0980	3.1029	3.1078	3.1127	3.1175	3.1224	2.1273
.96	3.1322	3.1371	3.1420	3.1469	3.1518	3.1567	3.1616	3.1665	3.1714	3.1764
.97	3.1813	3.1862	3.1911	3.1960	3.2010	3.2059	3.2108	3.2158	3.2207	3.2257
.98	3.2306	3.2355	3.2405	3.2454	3.2504	3.2554	3.2603	3.2653	3.2702	3.2752
.99	3.2802	3.2851	3.2901	3.2951	3.3001	3.3051	3.3100	3.3150	3.3200	3.3250

Table 39 (*Continued*)

Discharge in Cubic Feet per Second per Foot of Length over Sharp Crested Weirs, without Velocity of Approach Correction, by the Francis Formula $Q = 3.33H^{3/2}$

Head in feet	.000	.001	.002	.003	.004	.005	.006	.007	.008	.009
1.00	3.3300	3.3350	3.3400	3.3450	3.3500	3.3550	3.3600	3.3650	3.3700	3.3751
1.01	3.3801	3.3851	3.3901	3.3951	3.4002	3.4052	3.4102	3.4153	3.4203	3.4254
1.02	3.4304	3.4354	3.4405	3.4455	3.4506	3.4557	3.4607	3.4658	3.4708	3.4759
1.03	3.4810	3.4860	3.4911	3.4962	3.5013	3.5063	3.5114	3.5165	3.5216	3.5267
1.04	3.5318	3.5369	3.5420	3.5471	3.5522	3.5573	3.5624	3.5675	3.5726	3.5777
1.05	3.5828	3.5880	3.5931	3.5982	3.6033	3.6085	3.6136	3.6187	3.6239	3.6290
1.06	3.6342	3.6393	3.6444	3.6496	3.6547	3.6599	3.6651	3.6702	3.6754	3.6805
1.07	3.6857	3.6909	3.6960	3.7012	3.7064	3.7116	3.7167	3.7219	3.7271	3.7323
1.08	3.7375	3.7427	3.7479	3.7531	3.7583	3.7635	3.7687	3.7739	3.7791	3.7843
1.09	3.7895	3.7947	3.8000	3.8052	3.8104	3.8156	3.8209	3.8261	3.8313	3.8365
1.10	3.8418	3.8470	3.8523	3.8575	3.8628	3.8680	3.8733	3.8785	3.8838	3.8890
1.11	3.8943	3.8996	3.9048	3.9101	3.9154	3.9206	3.9259	3.9312	3.9365	3.9418
1.12	3.9470	3.9523	3.9576	3.9629	3.9682	3.9735	3.9788	3.9841	3.9894	3.9947
1.13	4.0000	4.0053	4.0106	4.0160	4.0213	4.0266	4.0319	4.0372	4.0426	4.0479
1.14	4.0532	4.0586	4.0639	4.0692	4.0746	4.0799	4.0853	4.0906	4.0960	4.1013
1.15	4.1067	4.1120	4.1174	4.1228	3.1281	4.1335	4.1389	4.1442	4.1496	4.1550
1.16	4.1604	4.1657	4.1711	4.1765	4.1819	4.1873	4.1927	3.1981	4.2035	4.2089
1.17	4.2143	4.2197	4.2251	4.2305	4.2359	4.2413	4.2467	4.2522	4.2576	4.2630
1.18	4.2684	4.2738	4.2793	4.2847	4.2901	4.2956	4.3010	4.3065	4.3119	4.3173
1.19	4.3228	4.3282	4.3337	4.3392	4.3446	4.3501	4.3555	4.3610	4.3665	4.3719
1.20	4.3774	4.3829	4.3883	4.3938	4.3993	4.4048	4.4103	4.4158	4.4212	4.4267
1.21	4.4322	4.4377	4.4432	4.4487	4.4542	4.4597	4.4652	4.4707	4.4763	4.4818
1.22	4.4873	4.4928	4.4983	4.5038	4.5094	4.5149	4.5204	4.5260	4.5315	4.5370
1.23	4.5426	4.5481	4.5537	4.5592	4.5647	4.5703	4.5759	4.5814	4.5870	4.5925
1.24	4.5981	4.6036	4.6092	4.6148	4.6203	4.6259	4.6315	4.6371	4.6427	4.6482
1.25	4.6538	4.6594	4.6650	4.6706	4.6762	4.6818	4.6874	4.6930	4.6986	4.7042
1.26	4.7098	4.7154	4.7210	4.7266	4.7322	4.7378	4.7435	4.7491	4.7547	4.7603
1.27	4.7660	4.7716	4.7772	4.7829	4.7885	4.7941	4.7998	4.8054	4.8111	4.8167
1.28	4.8224	4.8280	4.8337	4.8393	4.8450	4.8506	4.8563	4.8620	4.8676	4.8733
1.29	4.8790	4.8847	4.8903	4.8960	4.9017	4.9074	4.9131	4.9187	4.9244	4.9301
1.30	4.9358	4.9415	4.9472	4.9529	4.9586	4.9643	4.9700	4.9757	4.9814	4.9872
1.31	4.9929	4.9986	4.0043	5.0100	5.0158	5.0215	5.0272	5.0330	5.0387	5.0444
1.32	5.0502	5.0559	5.0616	5.0674	5.0731	5.0789	5.0846	5.0904	5.0961	5.1019
1.33	5.1077	5.1134	5.1192	5.1249	5.1307	5.1365	5.1423	5.1480	5.1538	5.1596
1.34	5.1654	5.1712	5.1769	5.1827	5.1885	5.1943	5.2001	5.2059	5.2117	5.2175
1.35	5.2233	5.2291	5.2349	5.2407	5.2465	4.2523	5.2582	5.2640	5.2698	5.2756
1.36	5.2814	5.2873	5.2931	5.2989	5.3048	5.3106	5.3164	5.3223	5.3281	5.3340
1.37	5.3398	5.3456	5.3515	5.3573	5.3632	5.3691	5.3749	5.3808	5.3866	5.3925
1.38	5.3984	5.4042	5.4101	5.4160	5.4219	5.4277	5.4336	5.4395	5.4454	5.4513
1.39	5.4572	5.4630	5.4689	5.4748	5.4807	5.4866	5.4925	5.4984	5.5043	5.5102
1.40	5.5162	5.5221	5.5280	5.5339	5.5398	5.5457	5.5516	5.5576	5.5635	5.5694
1.41	5.5754	5.5813	5.5872	5.5932	5.5991	5.6050	5.6110	5.6169	5.6229	5.6288
1.42	5.6348	5.6407	5.6467	5.6526	5.6586	5.6646	5.6705	5.6765	5.6825	5.6884
1.43	5.6944	5.7004	5.7064	5.7123	5.7183	5.7243	5.7303	5.7363	5.7423	5.7482
1.44	5.7542	5.7602	5.7662	5.7722	5.7782	5.7842	5.7902	5.7962	5.8023	5.8083
1.45	5.8143	5.8203	5.8263	5.8323	5.8384	5.8444	5.8504	5.8564	5.8625	5.8685
1.46	5.8745	5.8806	5.8866	5.8926	5.8987	5.9047	5.9108	5.9168	5.9229	5.9289
1.47	5.9350	5.9410	5.9471	5.9532	5.9592	5.9653	5.9714	5.9774	5.9835	5.9896
1.48	5.9957	6.0017	6.0078	6.0139	6.0200	6.0261	6.0322	6.0382	6.0443	6.0504
1.49	6.0565	6.0626	6.0687	6.0748	6.0809	6.0870	6.0931	6.0993	6.1054	6.1115

TABLE 39 (*Continued*)

DISCHARGE IN CUBIC FEET PER SECOND PER FOOT OF LENGTH OVER SHARP-CRESTED WEIRS, WITHOUT VELOCITY OF APPROACH CORRECTION, BY THE FRANCIS FORMULA $Q = 3.33H^{3/2}$

Head in feet	.000	.001	.002	.003	.004	.005	.006	.007	.008	.009
1.50	6.1176	6.1237	6.1298	6.1360	6.1421	6.1482	6.1543	6.1605	6.1666	6.1727
1.51	6.1789	6.1850	6.1912	6.1973	6.2034	6.2096	6.2157	6.2219	6.2280	6.2342
1.52	6.2404	6.2465	6.2527	6.2588	6.2650	6.2712	6.2773	6.2835	6.2897	6.2959
1.53	6.3020	6.3082	6.3144	6.3206	6.3268	6.3330	6.3391	6.3453	6.3515	6.3577
1.54	6.3639	6.3701	6.3763	6.3825	6.3887	6.3949	6.4012	6.4074	6.4136	6.4198
1.55	6.4260	6.4322	6.4385	6.4447	6.4509	6.4571	6.4634	6.4696	6.4758	6.4821
1.56	6.4883	6.4945	6.5008	6.5070	6.5133	6.5195	6.5258	6.5320	6.5383	6.5445
1.57	6.5508	6.5570	6.5633	6.5696	6.5758	6.5821	6.5884	6.5946	6.6009	6.6072
1.58	6.6135	6.6198	6.6260	6.6323	6.6386	6.6449	6.6512	6.6575	6.6638	6.6701
1.59	6.6764	6.6827	6.6890	6.6953	6.7016	6.7079	6.7142	6.7205	6.7268	6.7331
1.60	6.7394	6.7458	6.7521	6.7584	6.7647	6.7711	6.7774	6.7837	6.7901	6.7964
1.61	6.8027	6.8091	6.8154	6.8217	6.8281	6.8344	6.8408	6.8471	6.8535	6.8598
1.62	6.8662	6.8726	6.8789	6.8853	6.8916	6.8980	6.9044	6.9108	6.9171	6.9235
1.63	6.9299	6.9363	6.9426	6.9490	6.9554	6.9618	6.9682	6.9746	6.9810	6.9874
1.64	6.9937	7.0001	7.0065	7.0129	7.0193	7.0258	7.0322	7.0386	7.0450	7.0514
1.65	7.0578	7.0642	7.0706	7.0771	7.0835	7.0899	7.0963	7.1028	7.1092	7.1156
1.66	7.1221	7.1285	7.1349	7.1414	7.1478	7.1543	7.1607	7.1672	7.1736	7.1801
1.67	7.1865	7.1930	7.1994	7.2059	7.2124	7.2188	7.2253	7.2318	7.2382	7.2447
1.68	7.2512	7.2576	7.2641	7.2706	7.2771	7.2836	7.2901	7.2965	7.3030	7.3095
1.69	7.3160	7.3225	7.3290	7.3355	7.3420	7.3485	7.3550	7.3615	7.3680	7.3745
1.70	7.3810	7.3876	7.3941	7.4006	7.4071	7.4136	7.4201	7.4267	7.4332	7.4397
1.71	7.4463	7.4528	7.4593	7.4659	7.4724	7.4789	7.4855	7.4920	7.4986	7.5051
1.72	7.5117	7.5182	7.5248	7.5313	7.5379	7.5445	7.5510	7.5576	7.5641	7.5707
1.73	7.5773	7.5839	7.5904	7.5970	7.6036	7.6102	7.6167	7.6233	7.6299	7.6365
1.74	7.6431	7.6497	7.6563	7.6628	7.6694	7.6760	7.6826	7.6892	7.6958	7.7024
1.75	7.7091	7.7157	7.7223	7.7289	7.7355	7.7421	7.7487	7.7554	7.7620	7.7686
1.76	7.7752	7.7819	7.7885	7.7951	7.8018	7.8084	7.8150	7.8217	7.8283	7.8349
1.77	7.8416	7.8482	7.8549	7.8615	7.8682	7.8748	7.8815	7.8882	7.8948	7.9015
1.78	7.9081	7.9148	7.9215	7.9281	7.9348	7.9415	7.9482	7.9548	7.9615	7.9682
1.79	7.9749	7.9816	7.9882	7.9949	8.0016	8.0083	8.0150	8.0217	8.0284	8.0351
1.80	8.0418	8.0485	8.0552	8.0619	8.0686	8.0753	8.0820	8.0888	0.0955	8.1022
1.81	8.1089	8.1156	8.1223	8.1291	8.1358	8.1425	8.1493	8.1560	8.1627	8.1695
1.82	8.1762	8.1829	8.1897	8.1964	8.2032	8.2099	8.2167	8.2234	8.2302	8.2369
1.83	8.2437	8.2504	8.2572	8.2640	8.2707	8.2775	8.2842	8.2910	8.2978	8.3046
1.84	8.3113	8.3181	8.3249	8.3317	8.3385	8.3452	8.3520	8.3588	8.3656	8.3724
1.85	8.3792	8.3860	8.3928	8.3996	8.4064	8.4132	8.4200	8.4268	8.4336	8.4404
1.86	8.4472	8.4540	8.4608	8.4677	8.4745	8.4813	8.4881	8.4949	8.5018	8.5086
1.87	8.5154	8.5223	8.5291	8.5359	8.5428	8.5496	8.5564	8.5633	8.5701	8.5770
1.88	8.5838	8.5907	8.5975	8.6044	8.6112	8.6181	8.6250	8.6318	8.6387	8.6455
1.89	8.6524	8.6593	8.6661	8.6730	8.6799	8.6868	8.6936	8.7005	8.7074	8.7143
1.90	8.7212	8.7281	8.7349	8.7418	8.7487	8.7556	8.7625	8.7694	8.7763	8.7832
1.91	8.7901	8.7970	8.8039	8.8108	8.8177	8.8246	8.8316	8.8385	8.8454	8.8523
1.92	8.8592	8.8662	8.8731	8.8800	8.8869	8.8939	8.9008	8.9077	8.9147	8.9216
1.93	8.9285	8.9355	8.9424	8.9494	8.9563	8.9633	8.9702	8.9772	8.9841	8.9911
1.94	8.9980	9.0050	9.0119	9.0189	9.0259	9.0328	9.0398	9.0468	9.0537	9.0607
1.95	9.0677	9.0747	9.0816	9.0886	9.0956	9.1026	9.1096	9.1165	9.1235	9.1305
1.96	9.1375	9.1445	9.1515	9.1585	9.1655	9.1725	9.1795	9.1865	9.1935	9.2005
1.97	9.2075	9.2145	9.2216	9.2286	9.2356	9.2426	9.2496	9.2567	9.2637	9.2707
1.98	9.2777	9.2848	9.2918	9.2988	9.3059	9.3129	9.3199	9.3270	9.3340	9.3411
1.99	9.3481	9.3552	9.3622	9.3693	9.3763	9.3834	9.3904	9.3975	9.4045	9.4116

TABLE 39 (*Concluded*)

DISCHARGE IN CUBIC FEET PER SECOND PER FOOT OF LENGTH OVER SHARP-CRESTED WEIRS, WITHOUT VELOCITY OF APPROACH CORRECTION, BY THE FRANCIS FORMULA $Q = 3.33H^{3/2}$

Head in feet	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
2.0	9.419	9.489	9.560	9.631	9.703	9.774	9.846	9.917	9.989	10.062
2.1	10.134	10.206	10.279	10.352	10.425	10.498	10.571	10.645	10.718	10.792
2.2	10.866	10.940	11.015	11.089	11.164	11.239	11.314	11.389	11.464	11.540
2.3	11.615	11.691	11.767	11.843	11.920	11.996	12.073	12.150	12.227	12.304
2.4	12.381	12.459	12.536	12.614	12.692	12.770	12.848	12.927	13.005	13.084
2.5	13.163	13.242	13.321	13.401	13.480	13.560	12.640	13.720	13.800	13.880
2.6	13.961	14.041	14.122	14.203	14.284	14.365	14.447	14.528	14.610	14.692
2.7	14.774	14.856	14.938	15.021	15.103	15.186	15.269	15.352	15.435	15.519
2.8	15.602	15.686	15.769	15.853	15.938	16.022	16.106	16.191	16.275	16.360
2.9	16.445	16.530	16.616	16.701	16.787	16.872	16.958	17.044	17.130	17.217
3.0	17.303	17.390	17.476	17.563	17.650	17.738	17.825	17.912	18.000	18.088
3.1	18.176	18.264	18.352	18.440	18.528	18.617	18.706	18.795	18.884	18.973
3.2	19.062	19.151	19.241	19.331	19.421	19.511	19.601	19.691	19.781	19.872
3.3	19.963	20.053	20.144	20.235	20.327	20.418	20.509	20.601	20.693	20.785
3.4	20.877	20.969	21.061	21.154	21.246	21.339	21.432	21.525	21.618	21.711
3.5	21.805	21.898	21.992	22.085	22.179	22.273	22.368	22.462	22.556	22.651
3.6	22.746	22.840	22.935	23.031	23.126	23.221	23.317	23.412	23.508	23.604
3.7	23.700	23.796	23.892	23.989	24.085	24.182	24.279	24.376	24.473	24.570
3.8	24.667	24.765	24.862	24.960	25.058	25.156	25.254	25.352	25.450	25.549
3.9	25.647	25.746	25.845	25.944	26.043	26.142	26.241	26.341	26.440	26.540
4.0	26.640	26.740	26.840	26.940	27.041	27.141	27.242	27.342	27.443	27.544
4.1	27.645	27.746	27.848	27.949	28.051	28.152	28.254	28.356	28.458	28.560
4.2	28.663	28.765	28.868	28.970	29.073	29.176	29.279	29.382	29.486	29.589
4.3	29.693	29.796	29.900	30.004	30.108	30.212	30.316	30.420	30.525	30.630
4.4	30.734	30.839	30.944	31.049	31.154	31.260	31.365	31.471	31.576	31.682
4.5	31.788	31.894	32.000	32.106	32.213	32.319	32.426	32.532	32.639	32.746
4.6	32.853	32.961	33.068	33.175	33.283	33.391	33.498	33.606	33.714	33.822
4.7	33.931	34.039	34.147	34.256	34.365	34.473	34.582	34.691	34.801	34.910
4.8	35.019	35.129	35.238	35.348	35.458	35.568	35.678	35.788	35.898	36.009
4.9	36.119	36.230	36.341	36.451	36.562	36.674	36.785	36.896	37.007	37.119
5.0	37.230	37.342	37.454	37.566	37.678	37.790	37.903	38.015	38.128	38.240
5.1	38.353	38.466	38.579	38.692	38.805	38.918	39.032	39.145	39.259	39.373
5.2	39.487	39.601	39.715	39.829	39.943	40.058	40.172	40.287	40.401	40.516
5.3	40.631	40.746	40.861	40.977	41.092	41.207	41.323	41.439	41.554	41.670
5.4	41.787	41.903	42.019	42.135	42.252	42.368	42.485	42.602	42.719	42.835
5.5	42.952	43.070	43.187	43.304	43.422	43.539	43.657	43.775	43.893	44.011
5.6	44.129	44.247	44.366	44.484	44.603	44.722	44.840	44.959	45.078	45.197
5.7	45.317	45.436	45.555	45.675	45.794	45.914	46.034	46.154	46.274	46.394
5.8	46.514	46.635	46.755	46.876	46.996	47.117	47.238	47.359	47.480	47.601
5.9	47.723	47.844	47.965	48.087	48.208	48.330	48.452	48.574	48.696	48.818
6.0	48.941	49.063	49.186	49.308	49.431	49.554	49.677	49.800	49.923	50.046
6.1	50.169	50.293	50.416	50.540	50.664	50.787	50.911	51.036	51.160	51.284
6.2	51.408	51.532	51.657	51.782	51.906	52.031	52.156	52.281	52.406	52.531
6.3	52.657	52.782	52.908	53.034	53.159	53.285	53.411	53.537	53.663	53.789
6.4	53.916	54.042	54.168	54.295	54.422	54.549	54.676	54.803	54.930	55.057
6.5	55.184	55.312	55.439	55.567	55.694	55.822	55.950	56.078	56.206	56.334
6.6	56.462	56.591	56.719	56.848	56.977	57.105	57.234	57.363	57.492	57.621
6.7	57.751	57.880	58.009	58 139	58.269	58.398	58.528	58.658	58.788	58.918
6.8	59.048	59.179	59.309	59.440	59.570	59.701	59.831	50.962	60.093	60.224
6.9	60.356	60.487	60.618	60.750	60.881	61.013	61.145	61.276	61.408	61.540

Table 40.—Three-halves Powers of Numbers

No.	.000	.001	.002	.003	.004	.005	.006	.007	.008	.009
.00	.0000	.0000	.0001	.0002	.0003	.0004	.0005	.0006	.0007	.0009
.01	.0010	.0012	.0013	.0015	.0017	.0018	.0020	.0022	.0024	.0026
.02	.0028	.0030	.0033	.0035	.0037	.0040	.0042	.0044	.0047	.0049
.03	.0052	.0055	.0057	.0060	.0063	.0065	.0068	.0071	.0074	.0077
.04	.0080	.0083	.0086	.0089	.0092	.0095	.0099	.0102	.0105	.0108
.05	.0112	.0115	.0119	.0122	.0125	.0129	.0132	.0136	.0140	.0143
.06	.0147	.0151	.0154	.0158	.0162	.0166	.0170	.0173	.0177	0181
.07	.0185	.0189	.0193	.0197	.0201	.0205	.0210	.0214	.0218	.0222
.08	.0226	.0231	.0235	.0239	.0243	.0248	.0252	.0257	.0261	.0265
.09	.0270	.0275	.0279	.0284	.0288	.0293	.0297	.0302	.0307	.0312
.10	.0316	.0321	.0326	.0331	.0335	.0340	.0345	.0350	.0355	.0360
.11	.0365	.0370	.0375	.0380	.0385	.0390	.0395	.0400	.0405	.0411
.12	.0416	.0421	.0426	.0431	.0436	.0442	.0447	.0452	.0458	.0463
.13	.0469	.0474	.0480	.0485	.0491	.0496	.0502	.0507	.0513	.0518
.14	.0524	.0529	.0535	.0541	.0546	.0552	.0558	.0564	.0569	.0575
.15	.0581	.0587	.0593	.0598	.0604	.0610	.0616	.0622	.0628	.0634
.16	.0640	.0646	.0652	.0658	.0664	.0670	.0676	.0682	.0688	.0695
.17	.0701	.0707	.0713	.0720	.0726	.0732	.0738	.0745	.0751	.0757
.18	.0764	.0770	.0776	.0783	.0789	.0796	.0802	.0809	.0815	.0822
.19	.0828	.0835	.0841	.0848	.0854	.0861	.0868	.0874	.0881	.0888
.20	.0894	.0901	.0908	.0915	.0921	.0928	.0935	.0942	.0949	.0955
.21	.0962	.0969	.0976	.0983	.0990	.0997	.1004	.1011	.1018	.1025
.22	.1032	.1039	.1046	.1053	.1060	.1067	.1074	.1081	.1089	.1096
.23	.1103	.1110	.1118	.1125	.1132	.1139	.1146	.1154	.1161	.1168
.24	.1176	.1183	.1191	.1198	.1205	.1213	.1220	.1228	.1235	.1243
.25	.1250	.1258	.1265	.1273	.1280	.1288	.1295	.1303	.1311	.1318
.26	.1326	.1333	.1341	.1349	.1356	.1364	.1372	.1380	.1387	.1395
.27	.1403	.1411	.1419	.1426	.1434	.1442	.1450	.1458	.1466	.1474
.28	.1482	.1490	.1498	.1506	.1514	.1522	.1530	.1538	.1546	.1554
.29	.1562	.1570	.1578	.1586	.1594	.1602	.1611	.1619	.1627	.1635
.30	.1643	.1652	.1660	.1668	.1676	.1684	.1693	.1701	.1709	.1718
.31	.1726	.1734	.1743	.1751	.1760	.1768	.1776	.1785	.1793	.1802
.32	.1810	.1819	.1827	.1836	.1844	.1853	.1861	.1870	.1879	.1887
.33	.1896	.1904	.1913	.1922	.1930	.1939	.1948	.1956	.1965	.1974
.34	.1983	.1991	.2000	.2009	.2018	.2026	.2035	.2044	.2053	.2062
.35	.2071	.2080	.2089	.2097	.2106	.2115	.2124	.2133	.2142	.2151
.36	.2160	.2169	.2178	.2187	.2196	.2205	.2214	.2223	.2232	.2242
.37	.2251	.2260	.2269	.2278	.2287	.2296	.2306	.2315	.2324	.2333
.38	.2342	.2352	.2361	.2370	.2380	.2389	.2398	.2408	.2417	.2426
.39	.2436	.2445	.2454	.2464	.2473	.2483	.2492	.2501	.2511	.2520
.40	.2530	.2539	.2549	.2558	.2568	.2578	.2587	.2597	.2606	.2616
.41	.2625	.2635	.2645	.2654	.2664	.2674	.2683	.2693	.2703	.2712
.42	.2722	.2732	.2741	.2751	.2761	.2771	.2781	.2790	.2800	.2810
.43	.2820	.2830	.2840	.2849	.2859	.2869	.2879	.2889	.2899	.2909
.44	.2919	.2929	.2939	.2949	.2959	.2969	.2979	.2989	.2999	.3009
.45	.3019	.3029	.3039	.3049	.3059	.3069	.3079	.3089	.3100	.3110
.46	.3120	.3130	.3140	.3150	.3161	.3171	.3181	.3191	.3202	.3212
.47	.3222	.3232	.3243	.3253	.3263	.3274	.3284	.3294	.3305	.3315
.48	.3325	.3336	.3346	.3357	.3367	.3378	.3388	.3399	.3409	.3420
.49	.3430	.3441	.3451	.3462	.3472	.3483	.3493	.3504	.3514	.3525

TABLE 40 (*Continued*)

THREE-HALVES POWERS OF NUMBERS

No.	.000	.001	.002	.003	.004	.005	.006	.007	.008	.009
.50	.3536	.3546	.3557	.3567	.3578	.3589	.3599	.3610	.3621	.3631
.51	.3642	.3653	.3664	.3674	.3685	.3696	.3707	.3717	.3728	.3739
.52	.3750	.3761	.3773	.3782	.3793	.3804	.3815	.3826	.3837	.3847
.53	.3858	.3869	.3880	.3891	.3902	.3913	.3924	.3935	.3946	.3957
.54	.3968	.3979	.3990	.4001	.4012	.4023	.4035	.4046	.4057	.4068
.55	.4079	.4090	.4101	.4112	.4123	.4135	.4146	.4157	.4168	.4179
.56	.4191	.4202	.4213	.4224	.4236	.4247	.4258	.4269	.4281	.4292
.57	.4303	.4315	.4326	.4337	.4349	.4360	.4372	.4383	.4394	.4406
.58	.4417	.4429	.4440	.4451	.4463	.4474	.4486	.4497	.4509	.4520
.59	.4532	.4544	.4555	.4566	.4578	.4590	.4601	.4613	.4624	.4636
.60	.4648	.4659	.4671	.4682	.4694	.4706	.4718	.4729	.4741	.4752
.61	.4764	.4776	.4788	.4799	.4811	.4823	.4835	.4847	.4858	.4870
.62	.4882	.4894	.4906	.4917	.4929	.4941	.4953	.4965	.4977	.4988
.63	.5000	.5012	.5024	.5036	.5048	.5060	.5072	.5084	.5096	.5108
.64	.5120	.5132	.5144	.5156	.5168	.5180	.5192	.5204	.5216	.5228
.65	.5240	.5253	.5265	.5277	.5289	.5301	.5313	.5325	.5338	.5350
.66	.5362	.5374	.5386	.5399	.5411	.5423	.5435	.5447	.5460	.5472
.67	.5484	.5496	.5509	.5521	.5533	.5546	.5558	.5570	.5583	.5595
.68	.5607	.5620	.5632	.5645	.5657	.5669	.5682	.5694	.5707	.5719
.69	.5732	.5744	.5757	.5769	.5782	.5794	.5806	.5819	.5832	.5844
.70	.5857	.5869	.5882	.5894	.5907	.5919	.5932	.5945	.5957	.5970
.71	.5983	.5995	.6008	.6020	.6033	.6046	.6059	.6071	.6084	.6097
.72	.6109	.6122	.6135	.6148	.6160	.6173	.6186	.6199	.6212	.6224
.73	.6237	.6250	.6263	.6276	.6288	.6301	.6314	.6327	.6340	.6353
.74	.6366	.6379	.6392	.6404	.6417	.6430	.6443	.6456	.6469	.6482
.75	.6495	.6508	.6521	.6534	.6547	.6560	.6573	.6586	.6599	.6612
.76	.6626	.6639	.6652	.6665	.6678	.6691	.6704	.6717	.6730	.6744
.77	.6757	.6770	.6783	.6796	.6809	.6823	.6836	.6849	.6862	.6876
.78	.6889	.6902	.6915	.6929	.6942	.6955	.6968	.6982	.6995	.7008
.79	.7022	.7035	.7048	.7062	.7075	.7088	.7102	.7115	.7129	.7142
.80	.7155	.7169	.7182	.7196	.7209	.7223	.7236	.7250	.7263	.7276
.81	.7290	.7303	.7317	.7331	.7344	.7358	.7371	.7385	.7398	.7412
.82	.7425	.7439	.7453	.7466	.7480	.7493	.7507	.7521	.7534	.7548
.83	.7562	.7575	.7589	.7603	.7616	.7630	.7644	.7658	.7671	.7685
.84	.7699	.7712	.7726	.7740	.7754	.7768	.7781	.7795	.7809	.7823
.85	.7837	.7850	.7864	.7878	.7892	.7906	.7920	.7934	.7947	.7961
.86	.7975	.7989	.8003	.8017	.8031	.8045	.8059	.8073	.8087	.8101
.87	.8115	.8129	.8143	.8157	.8171	.8185	.8199	.8213	.8227	.8241
.88	.8255	.8269	.8283	.8297	.8311	.8326	.8340	.8354	.8368	.8382
.89	.8396	.8410	.8425	.8439	.8453	.8467	.8481	.8495	.8510	.8524
.90	.8538	.8552	.8567	.8581	.8595	.8609	.8624	.8638	.8652	.8667
.91	.8681	.8695	.8709	.8724	.8738	.8752	.8767	.8781	.8796	.8810
.92	.8824	.8839	.8853	.8868	.8882	.8896	.8911	.8925	.8940	.8954
.93	.8969	.8983	.8998	.9012	.9026	.9041	.9056	.9070	.9085	.9099
.94	.9114	.9128	.9143	.9157	.9172	.9186	.9201	.9216	.9230	.9245
.95	.9259	.9274	.9289	.9303	.9318	.9333	.9347	.9362	.9377	.9391
.96	.9406	.9421	.9435	.9450	.9465	.9480	.9494	.9509	.9524	.9539
.97	.9553	.9568	.9583	.9598	.9613	.9627	.9642	.9657	.9672	.9687
.98	.9702	.9716	.9731	.9746	.9761	.9776	.9791	.9806	.9821	.9835
.99	.9850	.9865	.9880	.9895	.9910	.9925	.9940	.9955	.9970	.9985

TABLE 40 (*Continued*)

THREE-HALVES POWERS OF NUMBERS

No.	.000	.001	.002	.003	.004	.005	.006	.007	.008	.009
1.00	1.0000	1.0015	1.0030	1.0045	1.0060	1.0075	1.0090	1.0105	1.0120	1.0135
1.01	1.0150	1.0165	1.0181	1.0196	1.0211	1.0226	1.0241	1.0256	1.0271	1.0286
1.02	1.0301	1.0317	1.0332	1.0347	1.0362	1.0377	1.0393	1.0408	1.0423	1.0438
1.03	1.0453	1.0468	1.0484	1.0499	1.0514	1.0530	1.0545	1.0560	1.0575	1.0591
1.04	1.0606	1.0621	1.0637	1.0652	1.0667	1.0683	1.0698	1.0713	1.0728	1.0744
1.05	1.0759	1.0775	1.0790	1.0805	1.0821	1.0836	1.0852	1.0867	1.0882	1.0898
1.06	1.0913	1.0929	1.0944	1.0960	1.0975	1.0991	1.1006	1.1022	1.1037	1.1053
1.07	1.1068	1.1084	1.1098	1.1114	1.1129	1.1146	1.1161	1.1177	1.1193	1.1208
1.08	1.1224	1.1239	1.1255	1.1271	1.1286	1.1302	1.1317	1.1333	1.1349	1.1364
1.09	1.1380	1.1396	1.1411	1.1427	1.1443	1.1458	1.1474	1.1490	1.1505	1.1521
1.10	1.1537	1.1553	1.1568	1.1584	1.1600	1.1616	1.1631	1.1647	1.1663	1.1679
1.11	1.1695	1.1710	1.1726	1.1742	1.1758	1.1774	1.1789	1.1805	1.1821	1.1837
1.12	1.1853	1.1869	1.1885	1.1901	1.1917	1.1932	1.1948	1.1964	1.1980	1.1996
1.13	1.2012	1.2028	1.2044	1.2060	1.2076	1.2092	1.2108	1.2124	1.2140	1.2156
1.14	1.2172	1.2188	1.2204	1.2220	1.2236	1.2252	1.2268	1.2284	1.2300	1.2316
1.15	1.2332	1.2349	1.2365	1.2381	1.2397	1.2413	1.2429	1.2445	1.2461	1.2477
1.16	1.2494	1.2510	1.2526	1.2542	1.2558	1.2574	1.2591	1.2607	1.2623	1.2639
1.17	1.2655	1.2672	1.2688	1.2704	1.2720	1.2737	1.2753	1.2769	1.2786	1.2802
1.18	1.2818	1.2834	1.2851	1.2867	1.2883	1.2900	1.2916	1.2932	1.2948	1.2965
1.19	1.2981	1.2998	1.3014	1.3030	1.3047	1.3063	1.3080	1.3096	1.3112	1.3129
1.20	1.3145	1.3162	1.3178	1.3195	1.3211	1.3228	1.3244	1.3261	1.3277	1.3294
1.21	1.3310	1.3327	1.3343	1.3360	1.3376	1.3393	1.3409	1.3426	1.3442	1.3459
1.22	1.3475	1.3492	1.3509	1.3525	1.3542	1.3558	1.3575	1.3591	1.3608	1.3625
1.23	1.3641	1.3658	1.3675	1.3691	1.3708	1.3725	1.3741	1.3758	1.3775	1.3791
1.24	1.3808	1.3825	1.3841	1.3858	1.3875	1.3892	1.3908	1.3925	1.3942	1.3959
1.25	1.3975	1.3992	1.4009	1.4026	1.4043	1.4059	1.4076	1.4093	1.4110	1.4127
1.26	1.4143	1.4160	1.4177	1.4194	1.4211	1.4228	1.4245	1.4262	1.4278	1.4295
1.27	1.4312	1.4329	1.4346	1.4363	1.4380	1.4397	1.4414	1.4431	1.4448	1.4465
1.28	1.4482	1.4499	1.4516	1.4533	1.4550	1.4567	1.4584	1.4601	1.4618	1.4635
1.29	1.4652	1.4669	1.4686	1.4703	1.4720	1.4737	1.4754	1.4771	1.4788	1.4805
1.30	1.4822	1.4839	1.4856	1.4874	1.4891	1.4908	1.4925	1.4942	1.4959	1.4976
1.31	1.4994	1.5011	1.5028	1.5045	1.5062	1.5080	1.5097	1.5114	1.5131	1.5148
1.32	1.5166	1.5183	1.5200	1.5217	1.5235	1.5252	1.5269	1.5286	1.5304	1.5321
1.33	1.5338	1.5356	1.5373	1.5390	1.5408	1.5425	1.5442	1.5460	1.5477	1.5494
1.34	1.5512	1.5529	1.5546	1.5564	1.5581	1.5599	1.5616	1.5633	1.5651	1.5668
1.35	1.5686	1.5703	1.5720	1.5738	1.5755	1.5773	1.5790	1.5808	1.5825	1.5843
1.36	1.5860	1.5878	1.5895	1.5913	1.5930	1.5948	1.5965	1.5983	1.6000	1.6018
1.37	1.6035	1.6053	1.6071	1.6088	1.6106	1.6123	1.6141	1.6158	1.6176	1.6194
1.38	1.6211	1.6229	1.6247	1.6264	1.6282	1.6300	1.6317	1.6335	1.6353	1.6370
1.39	1.6388	1.6406	1.6423	1.6441	1.6459	1.6476	1.6494	1.6512	1.6530	1.6547
1.40	1.6565	1.6583	1.6600	1.6618	1.6636	1.6654	1.6672	1.6689	1.6707	1.6725
1.41	1.6743	1.6761	1.6778	1.6796	1.6814	1.6832	1.6850	1.6868	1.6885	1.6903
1.42	1.6921	1.6939	1.6957	1.6975	1.6993	1.7011	1.7029	1.7046	1.7064	1.7082
1.43	1.7100	1.7118	1.7136	1.7154	1.7172	1.7190	1.7208	1.7226	1.7244	1.7262
1.44	1.7280	1.7298	1.7316	1.7334	1.7352	1.7370	1.7388	1.7406	1.7424	1.7442
1.45	1.7460	1.7478	1.7496	1.7515	1.7533	1.7551	1.7569	1.7587	1.7605	1.7623
1.46	1.7641	1.7659	1.7677	1.7696	1.7714	1.7732	1.7750	1.7768	1.7786	1.7805
1.47	1.7823	1.7841	1.7859	1.7877	1.7896	1.7914	1.7932	1.7950	1.7968	1.7987
1.48	1.8005	1.8023	1.8041	1.8060	1.8078	1.8096	1.8115	1.8133	1.8151	1.8169
1.49	1.8188	1.8206	1.8224	1.8243	1.8261	1.8279	1.8298	1.8316	1.8334	1.8353

TABLE 40 (*Continued*)

THREE-HALVES POWERS OF NUMBERS

No.	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
1.5	1.837	1.856	1.874	1.892	1.911	1.930	1.948	1.967	1.986	2.005
1.6	2.024	2.043	2.062	2.081	2.100	2.120	2.139	2.158	2.178	2.197
1.7	2.216	2.236	2.256	2.276	2.295	2.315	2.335	2.355	2.375	2.395
1.8	2.415	2.435	2.455	2.476	2.496	2.516	2.537	2.557	2.578	2.598
1.9	2.619	2.640	2.660	2.681	2.702	2.723	2.744	2.765	2.786	2.807
2.0	2.828	2.850	2.871	2.892	2.914	2.935	2.957	2.978	3.000	3.022
2.1	3.043	3.065	3.087	3.109	3.131	3.153	3.174	3.197	3.219	3.241
2.2	3.263	3.285	3.308	3.330	3.352	3.375	3.398	3.420	3.443	3.465
2.3	3.488	3.511	3.534	3.557	3.580	3.602	3.626	3.649	3.672	3.695
2.4	3.718	3.741	3.765	3.788	3.811	3.835	3.858	3.882	3.906	3.929
2.5	3.953	3.977	4.000	4.024	4.048	4.072	4.096	4.120	4.144	4.168
2.6	4.192	4.217	4.241	4.265	4.290	4.314	4.338	4.363	4.387	4.412
2.7	4.437	4.461	4.486	4.511	4.536	4.560	4.585	4.610	4.635	4.660
2.8	4.685	4.710	4.736	4.761	4.786	4.811	4.837	4.862	4.888	4.913
2.9	4.938	4.964	4.990	5.015	5.041	5.067	5.093	5.118	5.144	5.170
3.0	5.196	5.222	5.248	5.274	5.300	5.327	5.353	5.379	5.405	5.432
3.1	5.458	5.484	5.511	5.538	5.564	5.591	5.617	5.644	5.671	5.698
3.2	5.724	5.751	5.778	5.805	5.832	5.859	5.886	5.913	5.940	5.968
3.3	5.995	6.022	6.049	6.077	6.104	6.132	6.159	6.186	6.214	6.242
3.4	6.269	6.297	6.325	6.352	6.380	6.408	6.436	6.464	6.492	6.520
3.5	6.548	6.576	6.604	6.632	6.660	6.689	6.717	6.745	6.774	6.802
3.6	6.830	6.859	6.888	6.916	6.945	6.973	7.002	7.031	7.060	7.088
3.7	7.117	7.146	7.175	7.204	7.233	7.262	7.291	7.320	7.349	7.378
3.8	7.408	7.437	7.466	7.496	7.525	7.554	7.584	7.613	7.643	7.672
3.9	7.702	7.732	7.761	7.791	7.821	7.850	7.880	7.910	7.940	7.970
4.0	8.000	8.030	8.060	8.090	8.120	8.150	8.181	8.211	8.241	8.272
4.1	8.302	8.332	8.363	8.393	8.424	8.454	8.485	8.515	8.546	8.577
4.2	8.607	8.638	8.669	8.700	8.731	8.762	8.793	8.824	8.855	8.886
4.3	8.917	8.948	8.979	9.010	9.041	9.073	9.104	9.135	9.167	9.198
4.4	9.230	9.261	9.292	9.324	9.356	9.387	9.419	9.451	9.482	9.514
4.5	9.546	9.578	9.610	9.642	9.674	9.706	9.738	9.770	9.802	9.834
4.6	9.866	9.898	9.930	9.963	9.995	10.03	10.06	10.09	10.12	10.16
4.7	10.19	10.22	10.25	10.29	10.32	10.35	10.39	10.42	10.45	10.48
4.8	10.52	10.55	10.58	10.62	10.65	10.68	10.71	10.75	10.78	10.81
4.9	10.85	10.88	10.91	10.95	10.98	11.01	11.05	11.08	11.11	11.15
5.0	11.18	11.21	11.25	11.28	11.31	11.35	11.38	11.42	11.45	11.48
5.1	11.52	11.55	11.59	11.62	11.65	11.69	11.72	11.76	11.79	11.82
5.2	11.86	11.89	11.93	11.96	11.99	12.03	12.06	12.10	12.13	12.17
5.3	12.20	12.24	12.27	12.31	12.34	12.37	12.41	12.44	12.48	12.51
5.4	12.55	12.58	12.62	12.65	12.69	12.72	12.76	12.79	12.83	12.86
5.5	12.90	12.93	12.97	13.00	13.04	13.07	13.11	13.15	13.18	13.22
5.6	13.25	13.29	13.32	13.36	13.39	13.43	13.47	13.50	13.54	13.57
5.7	13.61	13.64	13.68	13.72	13.75	13.79	13.82	13.86	13.90	13.93
5.8	13.97	14.00	14.04	14.08	14.11	14.15	14.19	14.22	14.26	14.29
5.9	14.33	14.37	14.40	14.44	14.48	14.51	14.55	14.59	14.62	14.66
6.0	14.70	14.73	14.77	14.81	14.84	14.88	14.92	14.95	14.99	15.03
6.1	15.07	15.10	15.14	15.18	15.21	15.25	15.29	15.33	15.36	15.40
6.2	15.44	15.48	15.51	15.55	15.59	15.62	15.66	15.70	15.74	15.78
6.3	15.81	15.85	15.89	15.93	15.96	16.00	16.04	16.08	16.12	16.15
6.4	16.19	16.23	16.27	16.30	16.34	16.38	16.42	16.46	16.50	16.53

Table 40 (*Concluded*)

Three-halves Powers of Numbers

No.	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
6.5	16.57	16.61	16.65	16.69	16.72	16.76	16.80	16.84	16.88	16.92
6.6	16.96	16.99	17.03	17.07	17.11	17.15	17.19	17.22	17.26	17.30
6.7	17.34	17.38	17.42	17.46	17.50	17.54	17.58	17.62	17.65	17.69
6.8	17.73	17.77	17.81	17.85	17.89	17.93	17.97	18.01	18.05	18.09
6.9	18.12	18.16	18.20	18.24	18.28	18.32	18.36	18.40	18.44	18.48
7.0	18.52	18.56	18.60	18.64	18.68	18.72	18.76	18.80	18.84	18.88
7.1	18.92	18.96	19.00	19.04	19.08	19.12	19.16	19.20	19.24	19.28
7.2	19.32	19.36	19.40	19.44	19.48	19.52	19.56	19.60	19.64	19.68
7.3	19.72	19.76	19.80	19.85	19.89	19.93	19.97	20.01	20.05	20.09
7.4	20.13	20.17	20.21	20.25	20.29	20.33	20.38	20.42	20.46	20.50
7.5	20.54	20.58	20.62	20.66	20.70	20.75	20.79	20.83	20.87	20.91
7.6	20.95	20.99	21.03	21.08	21.12	21.16	21.20	21.24	21.28	21.32
7.7	21.37	21.41	21.45	21.49	21.53	21.58	21.62	21.66	21.70	21.74
7.8	21.78	21.83	21.87	21.91	21.95	21.99	22.04	22.08	22.12	22.16
7.9	22.20	22.25	22.29	22.33	22.37	22.42	22.46	22.50	22.54	22.58
8.0	22.63	22.67	22.71	22.75	22.80	22.84	22.88	22.93	22.97	23.01
8.1	23.05	23.10	23.14	23.18	23.22	23.27	23.31	23.35	23.40	23.44
8.2	23.48	23.52	23.57	23.61	23.65	23.70	23.74	23.78	23.83	23.87
8.3	23.91	23.96	24.00	24.04	24.09	24.13	24.17	24.22	24.26	24.30
8.4	24.35	24.39	24.43	24.48	24.52	24.56	24.61	24.65	24.69	24.74
8.5	24.78	24.83	24.87	24.91	24.96	25.00	25.04	25.09	25.13	25.18
8.6	25.22	25.26	25.31	25.35	25.40	25.44	25.48	25.53	25.57	25.62
8.7	25.66	25.71	25.75	25.79	25.84	25.88	25.93	25.97	26.02	26.06
8.8	26.10	26.15	26.19	26.24	26.28	26.33	26.37	26.42	26.46	26.51
8.9	26.55	26.60	26.64	26.69	26.73	26.78	26.82	26.87	26.91	26.96
9.0	27.00	27.04	27.09	27.14	27.18	27.23	27.27	27.3[illegible]	27.36	27.41
9.1	27.45	27.50	27.54	27.59	27.63	27.68	27.72	27.7[illegible]	27.81	27.86
9.2	27.90	27.95	28.00	28.04	28.09	28.13	28.18	28.22	28.27	28.32
9.3	28.36	28.41	28.45	28.50	28.54	28.59	28.64	28.68	28.73	28.77
9.4	28.82	28.87	28.91	28.96	29.00	29.05	29.10	29.14	29.19	29.23
9.5	29.28	29.33	29.37	29.42	29.47	29.51	29.56	29.61	29.65	29.70
9.6	29.74	29.79	29.84	29.88	29.93	29.98	30.02	30.07	30.12	30.16
9.7	30.21	30.26	30.30	30.35	30.40	30.44	30.49	30.54	30.58	30.63
9.8	30.68	30.73	30.77	30.82	30.87	30.91	30.96	31.01	31.06	31.10
9.9	31.15	31.20	31.24	31.29	31.34	31.38	31.43	31.48	31.53	31.58
10.0	31.62	31.67	31.72	31.77	31.81	31.86	31.91	31.96	32.00	32.05
10.1	32.10	32.15	32.19	32.24	32.29	32.34	32.38	32.43	32.48	32.53
10.2	32.58	32.62	32.67	32.72	32.77	32.82	32.86	32.91	32.96	33.01
10.3	33.06	33.10	33.15	33.20	33.25	33.30	33.35	33.39	33.44	33.49
10.4	33.54	33.59	33.64	33.68	33.73	33.78	33.83	33.88	33.93	33.98
10.5	34.02	34.07	34.12	34.17	34.22	34.27	34.32	34.36	34.41	34.46
10.6	34.51	34.56	34.61	34.66	34.71	34.76	34.80	34.85	34.90	34.95
10.7	35.00	35.05	35.10	35.15	35.20	35.25	35.30	35.34	35.39	35.44
10.8	35.49	35.54	35.59	35.64	35.69	35.74	35.79	35.84	35.89	35.94
10.9	35.99	36.04	36.09	36.14	36.18	36.23	36.28	36.33	36.38	36.43
11.0	36.48	36.53	36.58	36.63	36.68	36.73	36.78	36.83	36.88	36.93
11.1	36.98	37.03	37.08	37.13	37.18	37.23	37.28	37.33	37.38	37.43
11.2	37.48	37.53	37.58	37.63	37.68	37.73	37.78	37.83	37.88	37.94
11.3	37.99	38.04	38.09	38.14	38.19	38.24	38.29	38.34	38.39	38.44
11.4	38.49	38.54	38.59	38.64	38.69	38.74	38.80	38.85	38.90	38.95

TABLE 41.—PERCENTAGE OF ERROR IN DISCHARGE, FOR DIFFERENT DISCHARGES OVER RECTANGULAR WEIRS OF DIFFERENT LENGTHS AND RIGHT-ANGLED V-NOTCH WEIRS, RESULTING FROM VARIOUS ERRORS IN MEASURING HEAD

Discharge in second-feet Q	Error in head in feet	Weir 1 ft. long		Weir 2 ft. long		Weir 5 ft. long		Weir 10 ft. long		Right-angled V-notch wier	
		Head	Per cent. error in Q	Head	Per cent. error in Q	Head	Per cent. error in Q	Head	Per cent. error in Q	Head	Per cent. error in Q
0.05	0.001	0.06	2.6	0.04	4.0	0.02	8.0	0.01	12.0	0.20	1.2
	0.005		13.2		21.2		41.0		68.0		6.1
	0.010		26.6		43.6		85.0		144.0		12.2
0.10	0.001	0.09	1.6	0.06	2.6	0.03	5.0	0.02	8.0	0.27	0.9
	0.005		8.1		13.2		25.0		41.0		4.6
	0.010		16.4		26.6		51.5		85.0		9.1
0.50	0.001	0.27	0.5	0.17	0.9	0.09	1.6	0.06	2.6	0.52	0.5
	0.005		2.7		4.3		8.1		13.2		2.4
	0.010		5.5		8.7		16.4		26.6		4.8
	0.050		27.3		45.7		89.5				23.8
1.00	0.001	0.44	0.3	0.27	0.5	0.15	1.0	0.09	1.6	0.69	0.4
	0.005		1.7		2.7		5.0		8.1		1.8
	0.010		3.4		5.5		10.1		16.4		3.6
	0.050		17.0		27.3		53.6		89.5		18.0
2.50	0.001	0.82	0.2	0.51	0.3	0.27	0.5	0.17	0.9	1.00	0.3
	0.005		0.9		1.5		2.7		4.3		1.2
	0.010		1.8		3.0		5.5		8.7		2.5
	0.050		9.1		14.7		27.3		45.7		12.4
5.00	0.001	1.32	0.1	0.82	0.2	0.44	0.3	0.27	0.5	1.32	0.2
	0.005		0.6		0.9		1.7		2.7		0.9
	0.010		1.1		1.8		3.4		5.5		1.9
	0.050		5.6		9.1		17.0		27.3		9.3
10.00	0.001	2.11	0.1	1.32	0.1	0.71	0.2	0.44	0.3	1.75	0.1
	0.005		0.4		0.6		1.1		1.7		0.7
	0.010		0.7		1.1		2.1		3.4		1.5
	0.050		3.5		5.6		10.6		17.0		7.3
25.00	0.001	3.93	0.1	2.45	0.1	1.32	0.1	0.82	0.2	2.53	0.1
	0.005		0.2		0.3		0.6		0.9		0.5
	0.010		0.4		0.6		1.1		1.8		1.0
	0.050		1.8		3.0		5.6		9.1		5.0

CHAPTER V

WEIRS NOT SHARP-CRESTED

Weirs are frequently constructed in channels for the purpose of obtaining continuous records of discharge. In such cases it may be very difficult to maintain a thin-edged weir, due to damage from floating drift and ice and a more substantial weir with a thicker crest may be advisable. It is also often convenient to be able to use an existing weir or overflow dam for measuring discharge. Weirs, of various dimensions and shapes are used in hydraulic structures and in designing such structures it is important to be able to compute approximately the discharges over these weirs.

The amount of water which will pass over a weir, not sharp-crested, depends to a large extent upon the shape of its crest, and it is necessary to resort to experiment to determine the discharge over any particular shape. Inasmuch as the number of shapes of weirs is unlimited, it is not to be expected that experimental data are or ever will be available for them all. There are available, however, the results of several series of experiments on weirs of different cross-sections which furnish much valuable information for determining discharges over weirs of the same or similar shapes.

Formula for Determining Discharge

The following discussion is based upon the method given by Horton[1] for determining the discharge over weirs of irregular section. The base formula

$$Q = CLH^{3/2} \tag{1}$$

is assumed for all weirs, values of C being determined from experiments for the different types, and arranged in tables to correspond to different values of H.

[1] ROBERT E. HORTON: *Water Supply and Irrigation Paper* No. 200, U.S. Geological Survey, pp. 59–134.

Horton made a velocity of approach correction by adding $\frac{V^2}{2g}$ to the measured head before computing his value of C from the experimental results. This same method of correcting for velocity of approach should therefore be employed in using the values of C given in the following tables. Formula (1) with velocity of approach correction becomes

$$Q = CL\left(H + \frac{V^2}{2g}\right)^{3/2} \qquad (2)$$

Following the same line of reasoning given on page 69 for sharp-crested weirs, and using the nomenclature given on page 64, formula (2) may be written in the approximately equivalent form

$$Q = CLH^{3/2}\left(1 + 0.024\,C^2\,\frac{H^2}{d^2}\right) \qquad (3)$$

or if preferred

$$Q = CLH^{3/2}\left[1 + 0.024\,C^2\left(\frac{LH}{A}\right)^2\right] \qquad (3a)$$

Table 40, page 122, giving three-halves powers of numbers, will assist in the solution of the above formulas.

The available experiments are not extensive enough to provide for the determination of the effect of velocity of approach on weirs not sharp-crested. The tables of coefficients in this chapter probably apply more accurately where the velocity of approach is not high. From a consideration of conditions for sharp-crested weirs it appears that discharges, for high velocities of approach, will be somewhat greater than is given by formula (2).

Since experimental conditions will seldom be duplicated in practice it is probable that errors may result from the general use of the coefficients given in this chapter. Extreme accuracy, however, is not always necessary in design, where uncertainty as to the exact quantity of water to be provided for may exist. The available data will usually be sufficient, for comparing weir sections to determine the section which will best fulfil certain requirements; *e.g.*, the shape of crest that will give the maximum or the minimum discharge under a given head.

When a weir, other than a sharp-crested weir, is to be constructed for measuring water, an exact duplicate of some model for which experimental coefficients have been obtained should be used if possible. When overflow dams are used for gaging

9

streams, coefficients may be selected from the table for the weir section most closely resembling the section in question. For dams having irregular crests, or if experimental coefficients are not available for a model resembling the dam, it may be advisable to make a few discharge measurements of the stream and determine the values of coefficients corresponding to different heads through as wide a range of discharges as possible. Judgment and experience and an intimate knowledge of weir hydraulics are essential in selecting weir coefficients, similar to that required in selecting coefficients for pipe and open-channel formulas.

Modifications of the Nappe Form

The problem of establishing a fixed relation between head and discharge, for weirs not sharp-crested, is complicated by the fact that the nappe may assume a variety of forms in passing over the weir. For each modification of nappe form there is a corresponding change in the relation between head and discharge. The effect of this condition is more noticeable for low heads. The following is a discussion by Horton[1] on the effects of modification of nappe form.

The elaborate investigations of Bazin relative to the physics of weir discharge set forth clearly the importance of taking into consideration the particular form assumed by the nappe. This is especially true in weirs of irregular section in which there is usually more opportunity for change of form than for a thin-edged weir. In general the nappe may:

1. Discharge freely, touching only the upstream crest edge.
2. Adhere to top of crest.
3. Adhere to downstream face of crest.
4. Adhere to both top and downstream face.
5. Remain detached, but become wetted underneath.
6. Adhere to top, but remain detached from face and become wetted underneath.
7. In any of the cases where the nappe is "wetted underneath" this condition may be replaced by a depressed nappe, having air imprisoned underneath at less than atmospheric pressure.

[1] Robert E. Horton: *Water Supply and Irrigation Paper* No. 200, U.S. Geological Survey, pp. 60–61.

The nappe may undergo several of these modifications in succession as the head is varied. The successive forms that appear with an increasing stage may differ from those pertaining to similar stages with a decreasing head. The head at which the changes of nappe form occur vary with the rate of change of head, whether increasing or decreasing, and with other conditions.

The law of coefficients may be greatly modified or even reversed when a change of form takes place in the nappe. The coefficient curve for any form of weir having a stable nappe is a continuous, smooth line. When the nappe becomes depressed, detached, or wetted underneath during the progress of an experiment, the resulting coefficient curve may consist of a series of discontinuous or even disconnected arcs terminating abruptly in "*points d'arrêt,*" where the form of nappe changes. The modifications of nappe form are usually confined to comparatively low heads, the nappe sometimes undergoing several successive changes as the head increases from zero until a stable condition is reached, beyond which further increase of head produces no change. The condition of the nappe when depressed or wetted underneath can usually be restored to that of free discharge by providing adequate aeration.

Among weirs of irregular section there is a large class for which, from the nature of their section, the nappe can assume only one form unless drowned. Such weirs, it is suggested, may, if properly calibrated, equal or exceed the usefulness of the thin-edged weir for purposes of stream gaging, because of their greater stability of section and because the thin-edged weir is not free from modification of nappe form for low heads.

As an example, Bazin gives the following coefficients applying to a thin-edged weir 2.46 feet high, with a head of 0.656 foot, under various conditions:

Condition of nappe	Bazin coefficient m	$C = m\sqrt{2g}$
Free discharge, full aeration	0.433	3.47
Nappe depressed, partial vacuum underneath	0.460	3.69
Nappe wetted underneath, downstream water level, 0.42 foot below crest	0.497	3.99
Nappe adhering to downstream face of weir, ressault at a distance	0.554	4.45

These coefficients include velocity of approach effect, which tends to magnify their differences somewhat. There is, however, a range of 25 per cent. variation in discharge between the extremes.

The departure in the weir coefficient from that applying to a thin-edged weir, for most forms of weirs of irregular section, results from some permanent modification of the nappe form. Weirs with sloping upstream faces reduce the crest contraction, broad-crested weirs cause adherence of the nappe to the crest, aprons cause permanent adherence of the nappe to the downstream face.

Broad-Crested Weirs

A weir that is approximately rectangular in cross-section is called a broad-crested weir, and unless otherwise noted will be assumed to have vertical faces, a plane level crest and sharp right-angled corners. Fig. 31 represents a broad-crested

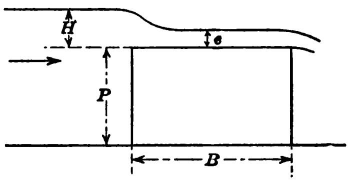


FIG. 31.—Broad-crested weir.

weir, having a height P and a breadth B. The head, H, should be measured at least $3H$ upstream from the weir. A short distance above the upper edge of the weir the water surface curves downward until a depth e is reached which depth remains nearly constant to a point near the lower edge of the weir.

Unwin[1] has shown that the theoretical formula for discharge over a broad-crested weir takes the form

$$Q = CLH^{3/2} \qquad (1)$$

and if the upstream corner of the weir is rounded sufficiently to overcome the effects of crest contraction while the crest of the weir is inclined slightly downward the theoretical value of C is 3.087. This value is seldom obtained in practice. For

[1] W. C. UNWIN: A Treatise on Hydraulics, p. 102.

broad-crested weirs, as for other weirs not sharp-crested, formula (1), page 128, is assumed and values of C corresponding to different values of B and H must be determined experimentally.

Experiments on broad-crested weirs have been performed by Blackwell, Bazin, the U. S. Deep Waterways Board, and the U. S. Geological Survey. These experiments cover a wide range of conditions as to head, breadth, and height of weir. Considerable discrepancy exists in the results of the different experimenters especially for heads below 0.5 feet. For heads from 0.5 to about 1.5 feet the coefficient becomes more uniform and for heads from 1.5 feet to the point where the nappe becomes detached from the crest of the weir the coefficient as given by the different experiments is nearly constant and equals approximately 2.63. When the head reaches from one to two times the breadth of the weir, the nappe becomes detached and the discharge is approximately equal to that for a sharp-crested weir. The degree of roughness of the crest, within reasonable limits, appears to have but little effect upon the discharge.

In order to put the results of the various experiments in a form convenient for use, Table 42, page 143, has been prepared by graphically interpolating the results of all experiments, giving more weight to those of the U. S. Geological Survey. This table should give values of C within the limits of accuracy of the original experiments. Velocity of approach correction should be made by formula (2) or (3), page 129. Table 40, page 122, gives three-halves powers of numbers.

Modifications of Broad-crested Weirs.—The effect of rounding the upstream corner of a broad-crested weir (Fig. 32), is to lower the weir by decreasing the crest contraction. In other words, rounding the upstream corner increases the discharge for a given head. Table 43, page 144, gives a résumé of experiments on this type of weir. From a comparison of these experiments with those for a broad-crested weir with sharp upstream corner it appears that the effect of rounding the upstream corner on a radius of 4 inches is to increase the coefficient, C, approximately 9 per cent. Experimental data for determining the effect of rounding the corner on a radius greater or less than 4 inches are not available.

Blackwell experimented with three weirs 3.0 feet broad having a slightly inclined crest, Fig. 33. The effect of inclining the crest is not quite clear from the experiments but appears to slightly increase the coefficient of discharge. The results of

these experiments are rather inconsistent, especially for low heads. Table 44, page 144, has been obtained from Blackwell's experiments.

The condition obtained by sloping the top of a broad-crested weir is similar to that of a triangular weir with the upstream face vertical. The coefficients given in Tables 45 and 46, pages 144 and 145, will therefore be valuable for selecting coefficients for broad-crested weirs with sloping crests.

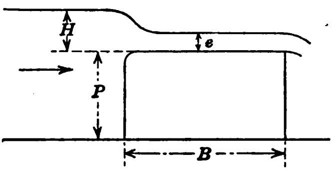


FIG. 32.—Broad-crested weir with upstream corner rounded.

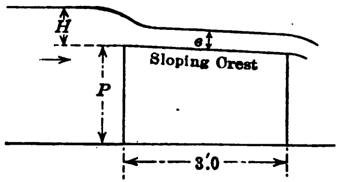


FIG. 33.—Broad-crested weir with sloping crest.

Weirs of Triangular Section

Fig. 34 represents the cross-section of a weir having the upper face vertical, and the lower face inclined downward; the two faces meeting in a sharp angle which forms the crest of the weir.

Bazin has experimented with weirs of this type, 2.46 feet high, giving various slopes to the downstream face. The

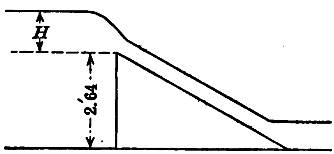


FIG. 34.—Triangular weir.

coefficients resulting from those experiments are given in Table 45, page 144.

It will be observed that the coefficient for a given slope in each case shown by the experiments is nearly constant for heads above 0.7 feet. It seems fair to assume, therefore, that these values could be extended to higher heads with reasonable assurance. The average values of the coefficients given in

Table 45, for heads above 0.7 feet were plotted logarithmically and found to fall very accurately on a straight line. This line was then extended to include slopes of 20 horizontal to 1 vertical from which the values given in Table 46, page 145, were taken. Table 46 may be used for computing discharges over weirs of the types shown in Fig. 33 or 34, for heads above 0.7 feet. These coefficients are to be used for broad-crested weirs with inclined tops only when the breadth is of sufficient width to prevent the nappe from springing clear; otherwise, the discharge will be approximately the same as for a thin-edged weir.

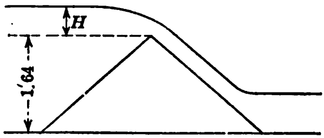


FIG. 35.—Triangular weir.

Bazin also experimented with weirs of triangular cross-sections, 1.64 feet high, having both faces inclined, Fig. 35. Coefficients to be used with the base formula, which cover the range of these experiments, are given in Table 47, page 145.

The velocity of approach correction for weirs of triangular section should be made in accordance with formula (2) or (3).

Weirs of Trapezoidal Section

Fig. 36 represents a weir of trapezoidal section with both upstream and downstream faces inclined. Experiments on

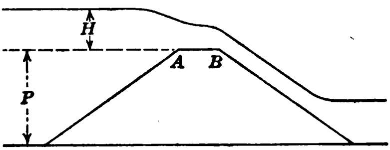


FIG. 36.—Trapezoidal weir.

this type of weir were made by Bazin and the United States Deep Waterways Board. Bazin's experiments were all on weirs 2.64 feet high, the breadth of crest varying from 0.66 to 1.32 feet. Two experiments on weirs of this type, each 4.9 feet high, were performed by the United States Deep Waterways Board.

Coefficients covering the range of Bazin's experiments are given in Table 48, page 146. Table 49, page 146, gives coefficients resulting from the experiments by the United States Deep Waterways Board.

For weirs of trapezoidal cross-section with sloping upstream and vertical downstream face, Fig. 37, there are five series of

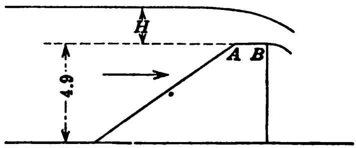


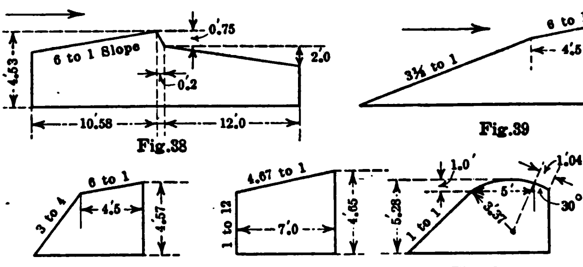
FIG. 37.—Trapezoidal weir.

experiments by the United States Deep Waterways Board. All of the models for these experiments were approximately 4.9 feet high and the breadth of crest AB was either 0.33 or 0.66 feet. The length of all weirs was 6.58 feet.

Table 50, page 147, gives coefficients derived from these experiments. Discharges over trapezoidal weirs should be corrected for velocity of approach by formula (2) or (3).

Weirs of Irregular Section

Figs. 38 to 42 inclusive represent models of weirs experimented upon by the U. S. Deep Waterways Board, under



FIGS. 38 TO 42.

the direction of G. W. Rafter, at the hydraulic laboratory of Cornell University. From four to seven experiments were run on each model, the range of head varying approximately

from 1 to 5.5 feet. Values of C tabulated from these experiments are given in Table 51, page 147.

Experiments on models of the old Croton dam (Figs. 43 to 47 inclusive) were made at Cornell University in 1899, for the

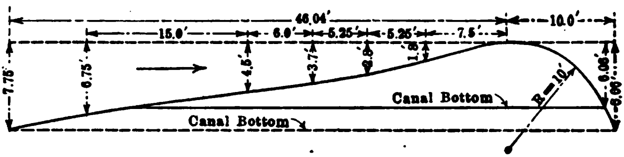


Fig. 43.

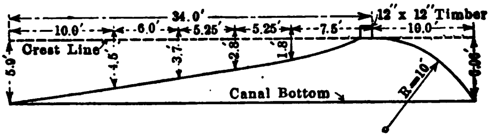


Fig. 44.

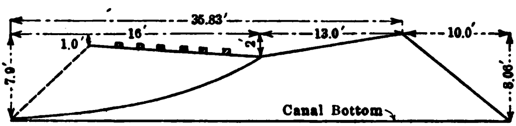


Fig. 45.

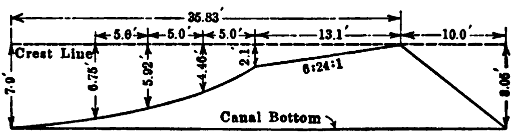


Fig. 46.

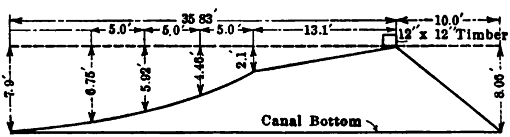


Fig. 47.

city of New York, under the direction of J. R. Freeman. The models were given different degrees of roughness to determine the effect of roughness of crest on discharge. Table 52, page 147, gives the tabulated results of these experiments.

Experiments for the U. S. Geological Survey, under the direction of Robert E. Horton, were performed in 1903 at the hydraulic laboratory of Cornell University to determine the coefficients of discharge of weirs modeled after various types of dams. Figs. 48 to 55 inclusive show forms of crests of

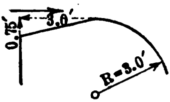


Fig. 48.

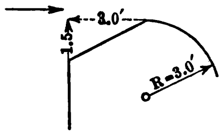


Fig. 49.

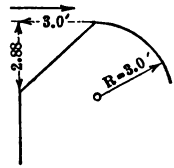


Fig. 50.

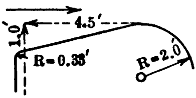


Fig. 51.

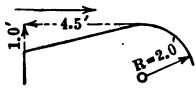


Fig. 52.

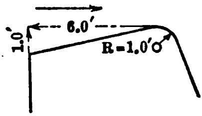


Fig. 53.

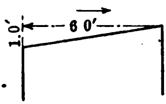


Fig. 54.

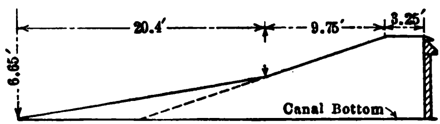


Fig. 55.

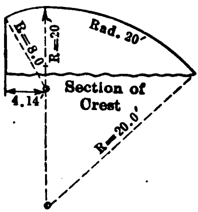


Fig. 56.

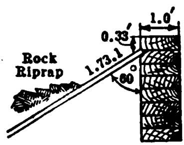


Fig. 57.

models experimented upon. The weirs were all 11.25 feet high and either 8 or 15 feet long. The purpose of the experiments was to enable the Geological Survey to more accurately determine discharges over weirs at gaging stations. Coefficients obtained from these experiments are given in Table 53, page 148.

Fig. 56 is a cross-section of the old dam at Austin, Texas. Five series of gagings of flow over this dam were made with a current meter by Taylor[1] in 1900. The range of head was from 0.42 to 1.44 feet.

Fig. 57 is a cross-section of the Blackstone River dam at Albion, Mass. Five current meter measurements of the water passing over this dam were made by Dwight Porter. The head in each case was about 1 foot and the resulting values of C vary from 3.41 to 3.94.

The last two lines in Table 53, page 148, give mean values of C as determined for measurement of flow over the above dams.

Submerged Weirs and Dams

There are three types of problems in connection with submerged weirs (not sharp-crested) or dams.

(*a*) To determine the discharge, the head and depth of submergence being given.

(*b*) To determine the height of dam necessary to raise the elevation of water surface a given amount.

(*c*) To determine the amount that a dam of a given height will raise the elevation of the water surface.

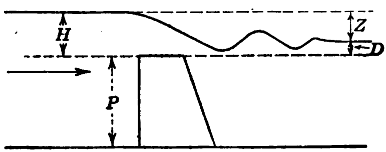


Fig. 58.—Submerged dam.

In general, the methods of solution will be the same as that already discussed (page 84) for sharp-crested submerged weirs. Fig. 58 represents such a weir or dam, H being the depth of water passing over the dam and D the depth of submergence, measured below all turbulence caused by the standing wave. The notation will be the same as that given on pages 64 and 65.

As already stated, page 83, a submerged-weir formula to be generally applicable must consider the channel dimensions above and below the weir. A weir coefficient must also be

[1] T. U. Taylor: The Austin Dam. *Water Supply and Irrigation Paper* No. 40.

selected for each shape of crest. For some weirs the problem is still farther complicated by the fact that not only the coefficient of discharge but the height of the standing wave may be affected by the form of the crest of the weir. Weirs with broad flat crests, either level or gently sloping, may have a standing wave form before the water is free from the weir. The effect of this condition is similar to reducing the depth of water in the channel below the weir. This will cause a higher standing wave than would form in the natural channel and result in a greater discharge for a given difference in elevation of water surfaces above and below the weir.

Bazin has experimented with a number of models of submerged weirs having heights of either 1.15 or 2.46 feet. Nelles[1] has prepared an abstract of Bazin's experiments on broad-crested weirs and weirs of triangular and trapezoidal cross-sections. Owing to the difficulties referred to above as well as the necessarily limited range of the experiments it is impossible to develop any working formula from these data. Each type of weir is a problem in itself and each requires an extensive investigation, covering a wide range of conditions. When it is considered that weir sections may be constructed in an indefinite number of shapes it may be seen that a most extensive set of experiments will be necessary before an understanding of this subject may be expected.

The author's formula for flow over sharp-crested submerged weirs (formula (41), page 82) using the nomenclature given on pages 64 and 65, is

$$Q = 3.34\, LZ^{1.47} \left(1 + \frac{1}{5}\sqrt{\frac{HD}{d_1 Z}}\right) \left(1 + 1.2\frac{D}{Z}\right) \left(1 + 0.56\frac{H^2}{d^2}\right) \quad (4)$$

From a study of Bazin's experiments it appears that all of the symbols in the above formula, and probably another which corrects for shape of crest, influence the discharge over submerged dams and weirs. In the light of present knowledge of the subject, however, it appears impossible to outline any definite method of procedure.

The author submits the following approximate rules for determining discharges over submerged dams and weirs not sharp-crested:

1. When D is not greater than $0.2H$, use the ordinary weir formula, $Q = CLH^{3/2}$, choosing the proper value of C from

[1] G. T. Nelles: Flow over Submerged Dams. *Trans.* Amer. Soc. Civ. Eng., vol. 44, pp. 362–383.

Tables 42 to 53 inclusive, and correction for velocity of approach if necessary by formula (2) or (3), page 129. Values of $H^{3/2}$ are given in Table 40, page 122.

2. For narrow weirs having a crest with a sharp upstream corner or for weirs of triangular section with the downstream face not flatter than 2 horizontal to 1 vertical, use formula (4).

3. For weirs with rounded crests not over 5 feet broad, increase results from formula (4) by 10 per cent.

4. For weirs with very broad crests or gently sloping downstream faces, increase results from formula (4) by from 10 to 30 per cent. or even more. The necessity of this correction is due largely to the fact that a standing wave may form on the crest of the weir.

In applying the above rules it should be remembered that D is the depth of submergence measured below all turbulence caused by the overfalling water. These rules provide for an approximate solution of all submerged-weir problems.

If it is required, from formula (4), to determine the height of dam of a given length, necessary to raise the water surface in a channel a given height, the discharge Q being known, Z is given and the areas of the channels above and below the weir, and therefore d and d_1 may be determined. Q may be corrected if necessary by the above rules. $D = H - Z$ and the only unknown quantity in the equation is H which may be determined from formula (4) by successive approximations.

A similar method may be employed to determine the amount which the water surface in a stream will be raised by a submerged weir of a given height. (See discussion page 84.)

Falls

A canal or chute may terminate abruptly in such a manner as to allow the water to fall freely over its end without any reduction of its section. A longitudinal section of a fall is shown in A, Fig. 59. The canal may be of any cross-section, the more common forms being rectangular or trapezoidal, as shown in B and C, Fig. 59.

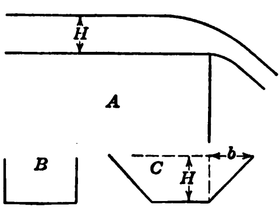


FIG. 59.—Fall.

There are no experimental data for determining the discharge corresponding to a given head, H, but an approximate solution

may be obtained by considering the fall a weir whose height equals zero. In this case d in formula (7) (page 72) becomes equal to H and the formula for a fall at the end of a channel of rectangular cross-section may be written

$$Q = 5.21LH^{1.47} \tag{5}$$

By assuming that the effects of contraction on the portion of the channel above the sloping sides will be similar to that on the rest of the channel, the formula for falls of trapezoidal cross-section, becomes approximately

$$Q = 5.21H^{1.47}(L + 0.8zH) \tag{6}$$

$z = \frac{b}{H}$ being the slopes of the sides of the channel. In formulas (5) and (6) H should be measured at least $3H$, and usually not more than 16 feet, above the crest of the fall.

The solution of the above formulas will be simplified by the use of Table 32, page 93.

Notch Falls or Drops.—In constructing canal systems it is frequently required to drop the water of a canal to a lower elevation and at the same time maintain a certain specified

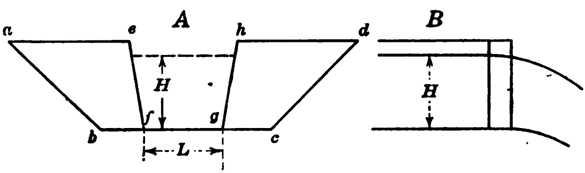


FIG. 60.—Notch fall or drop.

depth above the drop. This may be done by building a bulkhead across the canal, which contains a notch flush with the bottom of the canal. Fig. 60 represents such a structure, A being a cross-section and B a longitudinal section. The bulkhead across the canal section $abcd$ contains the notch $efgh$. L is the width of opening at the bottom of the notch and H is the depth of water in the canal above the structure. A and a represent respectively the cross-sectional areas of the channel and notch. The following formulas are based upon a study of the best available data but they lack direct experimental verification.

A and a represent respectively the cross-sectional areas below water level of the channel and the notch.

For rectangular notches, with upstream edges of sides rounded to suppress contractions

$$Q = 3.62LH^{1.47}\left(1 + 0.44\frac{a^2}{A^2}\right) \tag{7}$$

For rectangular notches with end contractions

$$Q = 3.62H^{1.47}(L - 0.2H)\left(1 + 0.44\frac{a^2}{A^2}\right) \tag{8}$$

For trapezoidal notches with end contractions suppressed, z being the slope of sides of notch, horizontal to vertical

$$Q = 3.62H^{1.47}(L + 0.8zH)\left(1 + 0.44\frac{a^2}{A^2}\right) \tag{9}$$

For trapezoidal notches with end contractions

$$Q = 3.62H^{1.47}(L + 0.8zH - 0.2H)\left(1 + 0.44\frac{a^2}{A^2}\right) \tag{10}$$

TABLE 42.—VALUES OF C IN THE FORMULA, $Q = CLH^{3/2}$ FOR BROAD-CRESTED WEIRS

Measured head in feet, H	Breadth of crest of weir in feet										
	0.50	0.75	1.00	1.50	2.00	2.50	3.00	4.00	5.00	10.00	15.00
0.2	2.80	2.75	2.69	2.62	2.54	2.48	2.44	2.38	2.34	2.49	2.68
0.4	2.92	2.80	2.72	2.64	2.61	2.60	2.58	2.54	2.50	2.56	2.70
0.6	3.08	2.89	2.75	2.64	2.61	2.60	2.68	2.69	2.70	2.70	2.70
0.8	3.30	3.04	2.85	2.68	2.60	2.60	2.67	2.68	2.68	2.69	2.64
1.0	3.32	3.14	2.98	2.75	2.66	2.64	2.65	2.67	2.68	2.68	2.63
1.2	3.32	3.20	3.08	2.86	2.70	2.65	2.64	2.67	2.66	2.69	2.64
1.4	3.32	3.26	3.20	2.92	2.77	2.68	2.64	2.65	2.65	2.67	2.64
1.6	3.32	3.29	3.28	3.07	2.89	2.75	2.68	2.66	2.65	2.64	2.63
1.8	3.32	3.32	3.31	3.07	2.88	2.74	2.68	2.66	2.65	2.64	2.63
2.0	3.32	3.31	3.30	3.03	2.85	2.76	2.72	2.68	2.65	2.64	2.63
2.5	3.32	3.32	3.31	3.28	3.07	2.89	2.81	2.72	2.67	2.64	2.63
3.0	3.32	3.32	3.32	3.32	3.20	3.05	2.92	2.73	2.66	2.64	2.63
3.5	3.32	3.32	3.32	3.32	3.32	3.19	2.97	2.76	2.68	2.64	2.63
4.0	3.32	3.32	3.32	3.32	3.32	3.32	3.07	2.79	2.70	2.64	2.63
4.5	3.32	3.32	3.32	3.32	3.32	3.32	3.32	2.88	2.74	2.64	2.63
5.0	3.32	3.32	3.32	3.32	3.32	3.32	3.32	3.07	2.79	2.64	2.63
5.5	3.32	3.32	3.32	3.32	3.32	3.32	3.32	3.32	2.88	2.64	2.63

TABLE 43.—VALUES OF C IN THE FORMULA, $Q = CLH^{3/2}$ FOR MODELS OF BROAD-CRESTED WEIRS WITH ROUNDED UPSTREAM CORNER

Name of experimenter	Radius of curve in feet	Breadth of weir in feet, B	Height of weir in feet, P	Head in feet, H									
				0.4	0.6	0.8	1.0	1.5	2.0	2.5	3.0	4.0	5.0
Bazin..........	0.33	2.62	2.46	2.93	2.97	2.98	3.01	3.04					
Bazin..........	0.33	6.56	2.46	2.70	2.82	2.87	2.89	2.92					
U. S. Deep Waterways...	0.33	2.62	4.57	....	2.77	2.80	2.83	2.92	3.00	3.08	3.17	3.34	3.50
U. S. Deep Waterways...	0.33	6.56	4.56	....	....	2.83	2.83	2.83	2.82	2.82	2.82	2.82	2.81

TABLE 44.—VALUES OF C IN THE FORMULA, $Q = CLH^{3/2}$ FOR BROAD-CRESTED WEIRS WITH CRESTS INCLINED SLIGHTLY DOWNWARD

Slope of crest	Length of weir in feet	Head in feet, H						
		0.1	0.2	0.3	0.4	0.5	0.6	0.7
12 to 1............	3.0	2.58	2.87	2.57	2.60	2.84	2.81	2.70
18 to 1............	3.0	2.91	2.92	2.53	2.60	2.80	2.74	2.62
18 to 1............	10.0	2.52	2.68	2.73	2.80	2.90	2.80	2.68

TABLE 45.—VALUES OF C IN THE FORMULA $Q = CLH^{3/2}$ FOR WEIRS OF TRIANGULAR CROSS-SECTION WITH VERTICAL UPSTREAM FACE AND SLOPING DOWNSTREAM FACE

Slope of down-stream face	Height of weir in feet, P	Head in feet, H										
		0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.2	1.5
Hor. Vert.												
1 to 1	2.46	3.88	3.85	3.85	3.85	3.85	3.85	3.85	3.85	3.85	3.85	3.85
2 to 1	2.46	3.48	3.48	3.49	3.49	3.50	3.50	3.50	3.50	3.50	3.51	3.51
2 to 1	1.64	3.56	3.47	3.47	3.51	3.54	3.57	3.58	3.58	3.58	3.59	3.57
3 to 1	1.64	....	2.90	3.11	3.22	3.26	3.33	3.37	3.40	3.40	3.41	3.41
5 to 1	2.46	....	3.08	3.06	3.05	3.05	3.07	3.09	3.12	3.13	3.13	3.13
10 to 1	2.46	....	2.82	2.83	2.84	2.86	2.89	2.90	2.91	2.91	2.92	2.93

TABLE 46.—VALUES OF C IN THE FORMULA $Q = CLH^{3/2}$, BEING THE MEAN AND EXTENSION OF EXPERIMENTAL RESULTS, ON WEIRS OF TRIANGULAR CROSS-SECTION WITH VERTICAL UPSTREAM FACE AND SLOPING DOWNSTREAM FACE. THIS TABLE SHOULD BE USED ONLY FOR HEADS ABOVE 0.7 FOOT

Slope of downstream face	Value of C	Slope of downstream face	Value of C	Slope of downstream face	Value of C
Hor. Vert.		Hor. Vert.		Hor. Vert.	
1 to 1	3.85	6 to 1	3.07	12 to 1	2.86
2 to 1	3.54	7 to 1	3.02	14 to 1	2.80
3 to 1	3.35	8 to 1	2.98	16 to 1	2.76
4 to 1	3.21	9 to 1	2.94	18 to 1	2.72
5 to 1	3.13	10 to 1	2.92	20 to 1	2.69

TABLE 47.—VALUES OF C IN THE FORMULA $Q = CLH^{3/2}$ FOR WEIRS OF TRIANGULAR CROSS-SECTION WITH BOTH FACES INCLINED. FOR HEADS ABOVE 1.5 FEET USE THE VALUE OF C GIVEN FOR A HEAD OF 1.5 FEET

Slope of up-stream face	Slope of down-stream face	Head in feet, H										
		0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.2	1.5
Hor. Vert.	Hor. Vert.											
1 to 1	1 to 1	....	4.26	4.20	4.14	4.11	4.11	4.11	4.10	4.08	3.93	3.75
1 to 1	2 to 1	3.82	3.80	3.77	3.77	3.79	3.82	3.84	3.85	3.85	3.85	3.84
1 to 1	3 to 1	....	3.55	3.52	3.48	3.46	3.45	3.46	3.47	3.48	3.47	3.46
2 to 1	2 to 1	3.88	3.85	3.83	3.81	3.81	3.83	3.86	3.87	3.87	3.87	3.87
1 to 1	2 to 1	3.82	3.81	3.77	3.77	3.78	3.82	3.83	3.84	3.84	3.84	3.84
1 to 2	2 to 1	3.74	3.71	3.68	3.69	3.72	3.73	3.73	3.74	3.74	3.73	3.71
1 to 3	2 to 1	3.65	3.64	3.64	3.67	3.68	3.69	3.69	3.69	3.69	3.68	3.66
Vertical	2 to 1	3.56	3.47	3.47	3.51	3.54	3.57	3.58	3.58	3.58	3.59	3.57

TABLE 48.[1]—VALUES OF C IN THE FORMULA $Q = CLH^{3/2}$ FOR WEIRS OF TRAPEZOIDAL CROSS-SECTION WITH BOTH FACES INCLINED. THIS TABLE INDICATES THAT VALUES OF C INCREASE SLIGHTLY FOR HEADS ABOVE 1.5 FEET

Slope of up-stream face	Slope of down-stream face	Width of crest in feet	Head in feet, H										
			0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.2	1.5
Hor. Vert.	Hor. Vert.												
1 to 2	1 to 1	0.66	2.70	2.82	2.89	3.02	3.13	3.24	3.34	3.44	3.52	3.66	3.82
1 to 2	2 to 1	0.66	2.71	2.79	2.83	2.92	3.03	3.14	3.27	3.32	3.38	3.50	3.61
1 to 2	3 to 1	0.66	2.70	2.76	2.80	2.91	3.00	3.07	3.14	3.21	3.27	3.37	3.45
1 to 2	4 to 1	0.66	2.71	2.74	2.84	2.88	2.98	3.06	3.12	3.17	3.21	3.28	3.35
1 to 2	5 to 1	0.66	2.71	2.80	2.86	2.88	2.93	3.02	3.08	3.12	3.17	3.23	3.26
1 to 2	2 to 1	1.32	....	2.71	2.77	2.80	2.80	2.84	2.88	2.93	2.98	3.08	3.22
1 to 2	4 to 1	1.32	....	2.76	2.80	2.82	2.82	2.85	2.88	2.91	2.94	3.01	3.10
1 to 2	6 to 1	1.32	....	....	2.79	2.80	2.82	2.85	2.87	2.90	2.93	2.98	3.08
2 to 1	2 to 1	0.67	2.82	2.94	3.04	3.13	3.20	3.26	3.32	3.38	3.43	3.51	3.61
1 to 1	2 to 1	0.67	2.73	2.86	2.92	3.02	3.12	3.21	3.29	3.36	3.42	3.53	3.65
1 to 3	2 to 1	0.67	2.50	2.62	2.75	2.87	2.99	3.09	3.18	3.27	3.34	3.46	3.55
Vertical	2 to 1	0.67	2.55	2.58	2.66	2.77	2.90	2.99	3.09	3 18	3.26	3.39	3.51

TABLE 49.[2]—VALUES OF C IN THE FORMULA $Q = CLH^{3/2}$ FOR WEIRS OF TRAPEZOIDAL CROSS-SECTION WITH BOTH FACES INCLINED

Slope of upstream face	Slope of down-stream face	Width of crest in feet	Head in feet, H									
			1.6	1.8	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5
Hor. Vert.	Hor. Vert.											
2 to 1	2 to 1	0.67	3.57	3.56	3.56	3.57	3.58	3.60	3.62	3.65	3.68	3.70
2 to 1	5 to 1	0.33	3.58	3.56	3.53	3.48	3.44	3.43	3.48	3.54	3.57	3.58

[1] See also Table 49.

[2] See also Table 48

TABLE 50.—VALUES OF C IN THE FORMULA $Q = CLH^{3/2}$ FOR WEIRS OF TRAPEZOIDAL CROSS-SECTION WITH THE UPSTREAM FACE INCLINED AND THE DOWNSTREAM FACE VERTICAL

Slope of upstream face	Width of crest in feet	Head in feet, H								
		1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
Hor. Vert.										
2 to 1	0.33	3.85	3.82	3.79	3.77	3.75	3.73	3.70	3.67	3.64
2 to 1	0.66	3.41	3.57	3.65	3.70	3.72	3.72	3.73	3.73	3.73
3 to 1	0.66	....	....	3.57	3.57	3.57	3.57	3.57	3.57	3.57
4 to 1	0.66	....	....	3.48	3.48	3.48	3.48	3.48	3.48	3.48
5 to 1	0.66	....	....	3.39	3.39	3.39	3.39	3.39	3.39	3.39

TABLE 51.—VALUES OF C IN THE FORMULA $Q = CLH^{3/2}$ FOR WEIRS OF IRREGULAR CROSS-SECTION

No. of figure	Head in feet, H									
	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5
38	3.13	3.22	3.22	3.22	3.22	3.22	3.22	3.22	3.22	3.22
39	.....	3.41	3.35	3.30	3.33	3.37	3.38	3.38	3.38	3.38
40	3.47	3.46	3.41	3.35	3.32	3.33	3.37	3.41	3.46	
41	.....	.....	.....	3.44	3.39	3.38	3.38	3.39	3.41	
42	3.28	3.29	3.32	3.39	3.46	3.51	3.59	3.62	3.65	

TABLE 52.—VALUES OF C IN THE FORMULA $Q = CLH^{3/2}$ FROM EXPERIMENTS AT CORNELL UNIVERSITY ON MODELS OF OLD CROTON DAM

No. of figure	Description of model	Head in feet, H								
		0.2	0.4	0.6	0.8	1.0	1.5	2.0	2.5	3.0
43	Made of smooth pine........	3.37	3.27	3.21	3.21	3.21	3.21	3.21	3.21	3.21
43	Made of unplaned plank......	....	2.89	2.94	2.99	3.03	3.11	3.14	3.15	
43	Rough slope—smooth crest...	....	3.19	3.19	3.19	3.20	3.20	3.21	3.21	3.22
43	Rough slope—Wire cloth on crest................	3.16	3.10	3.10	3.14	3.15	3.15	3.15	3.15	3.15
44	Made of unplaned plank.....	3.60	3.62	3.64	3.66	3.67	3.69	3.70		
44	Rough slope—Crest unplaned plank..............	....	....	3.66	3.66	3.66	3.66	3.66		
44	Rough slope—wire cloth on crest................	3.57	3.58	3.58	3.59	3.59	3.60	3.61		
45		3.30	3.08	3.01	3.05	3.18	3.37	3.46	3.48	3.49
46		....	3.59	3.47	3.44	3.50	3.69			
47	End *a* open..................	3.53	3.50	3.46	3.43	3.41	3.36	3.33	3.32	
47	End *a* with sloping approach		3.60	3.57	3.53	3.50	3.43	3.37		

TABLE 53.—VALUES OF C IN THE FORMULA $Q = CLH^{3/2}$ FROM EXPERIMENTS AT CORNELL UNIVERSITY ON MODELS RESEMBLING EXISTING DAMS (EXCEPT THAT THE LAST TWO EXPERIMENTS WERE MADE ON ACTUAL DAMS)

No. of figure	Length of model in feet	Head in feet, H									
		0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5 0
48	7.94	....	3.30	3.32	3.36	3.40	3.43	3.48	3.53	3.62	3.70
48	15.97	3.32	3.44	3.46	3.42	3.41	3.46	3.50			
49	7.98	....	3.38	3.46	3.51	3.55	3.58	3.62	3.68	3.74	3.83
49	15.97	3.22	3.48	3.61	3.67	3.70	3.72				
50	15.97	3.15	3.45	3.64	3.75	3.82	3.87	3.88			
51	15.97	3.18	3.32	3.43	3.52	3.59	3.64				
52	15.97	3.18	3.30	3.37	3.42	3.46	3.49	3.52	3.54		
53	15.97	3.28	3.50	3.54	3.52	3.36	3.31	3.30			
54	15.97	3.53	3.54	3.55	3.50	3.35	3.27	3.25	3.25		
55	15.93	3.13	3.14	3.10	3.41	3.20	3.26	3.31	3.37		
56	....	3.09	3.11	3.33							
57	....	....	3.80								

CHAPTER VI

FLOW OF WATER THROUGH PIPES

Fundamental Principles.—Fig. 61 represents a pipe line fed by a reservoir in which the water surface is maintained at a constant elevation. The discharge from the outlet P will be

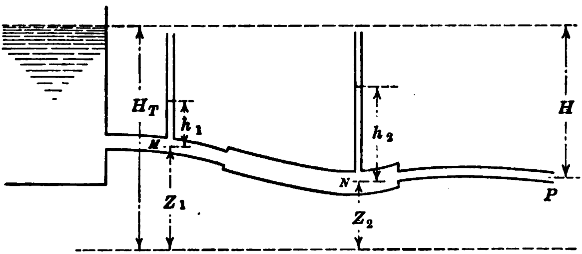


FIG. 61.

constant after a condition of equilibrium has been established. It is evident that the same quantity of water is then passing any section of the pipe. If v_1 and v_2 be mean velocities at any two sections M and N, and A_1 and A_2 the respective areas of sections, this relation is expressed by the equations

$$Q = A_1 v_1 = A_2 v_2 \tag{1}$$

also

$$v_1 = \frac{Q}{A_1} \text{ and } v_2 = \frac{Q}{A_2} \tag{2}$$

Bernoulli's theorem is the basis of all formulas for determining the flow of water through pipes. It assumes the ideal conditions of stream line motion and no friction losses. Referring to Fig. 61, Bernoulli's theorem may be expressed by the following equation which relation holds for any sections of the pipe.

$$H_T = h_1 + \frac{v_1^2}{2g} + Z_1 = h_2 + \frac{v_2^2}{2g} + Z_2 \tag{3}$$

In the application of Bernoulli's theorem to practical problems, allowance must be made for friction losses. The inner surface of a pipe always resists the movement of water, which

resistance increases with the roughness of the material of which the pipe is constructed. Obstructions in pipes such as valves, bends, and contractions or enlargements cause an additional resistance to flow. This resistance has the effect of reducing the effective head and such losses of head are commonly spoken of as friction losses.

Bernoulli's theorem may be corrected to include friction losses. Considering M and N any two sections of a pipe, Fig. 61, if H_a represents the losses due to all causes between these sections, the equation may be written

$$h_1 + \frac{v_1^2}{2g} + Z_1 = h_2 + \frac{v_2^2}{2g} + Z_2 + H_a \tag{4}$$

If H represents the difference in elevation between the water surface in the reservoir and the outlet end of the pipe, and v the velocity with which the water leaves the pipe Bernoulli's equation for all losses in the pipe reduces to

$$H = H_a + \frac{v^2}{2g}. \tag{5}$$

In other words, the total head is equal to the sum of the lost heads and the velocity head at the point of discharge.

It is now necessary to analyze separately the various factors entering into the term H_a. The following notation will be used:

H_0 = Loss of head at entrance to pipe.
H_1 = Total loss of head due to friction between water and pipe.
H_2 = Loss of head due to enlargements of pipe.
H_3 = Loss of head due to contractions of pipe.
H_4 = Loss of head due to valves.
H_5 = Loss of head due to bends in pipe.

The complete equation for head lost in a pipe may be written

$$H_a = H_0 + H_1 + H_2 + H_3 + H_4 + H_5 \tag{6}$$

and the equation for total head is

$$H = \frac{v^2}{2g} + H_0 + H_1 + H_2 + H_3 + H_4 + H_5 \tag{7}$$

In the above equation v is the velocity at which the water leaves the pipe, or if the pipe is of uniform diameter throughout it is also the entrance velocity. In long pipes, that is pipes having a length of 500 diameters or more, H_1 is by far the most important consideration. Frequently with very long

pipes the other losses are so small a percentage of the total loss in head that they may be neglected. In the case of short pipes, however, all losses should be carefully analyzed.

In certain problems it may be found more convenient to express formula (7) in the form

$$H = \frac{v^2}{2g} + K_0\frac{v^2}{2g} + H_1 + K_2\frac{v^2}{2g} + K_3\frac{v^2}{2g} + K_4\frac{v^2}{2g} + K_5\frac{v^2}{2g} \qquad (8)$$

In this formula v is the velocity in the part of the pipe being considered, and in the case of loss of head due to enlargement or contraction, v will be the velocity in the smaller pipe. For a system of pipes of different diameters the velocity in one pipe may be expressed in terms of velocity in any other pipe by means of the simple relation that the velocities in the two pipes vary inversely as the squares of their respective diameters. The use of formula (8) will frequently be simplified by expressing all losses of head in terms of one value of v.

Loss of Head at Entrance to Pipes

The upper end of a pipe for a distanee of 2 or 3 diameters below the entrance is similar to a short tube and the head lost in this portion of a pipe is comparable to the loss in a short tube (page 41). If h is the head producing the discharge, v the mean velocity at the entrance to the pipe and C the coefficient of discharge,

$$v = C\sqrt{2gh},$$

and

$$h = \frac{1}{C^2}\cdot\frac{v^2}{2g}$$

since h is the sum of the velocity head and the head lost at entrance,

$$H_0 = \frac{1}{C^2}\cdot\frac{v^2}{2g} - \frac{v^2}{2g} = \left(\frac{1}{C^2} - 1\right)\frac{v^2}{2g} \qquad (9)$$

or, if

$$K_0 = \frac{1}{C^2} - 1 \qquad (10)$$

$$H_0 = K_0\frac{v^2}{2g} \qquad (11)$$

since C is equal to approximately 0.82 for a sharp-cornered entrance, K_0 under these conditions will be approximately 0.50. This value will be reduced by rounding the entrance

corners and it approaches zero for a bell-mouth entrance. The maximum value of K_0 occurs for an inward projecting entrance (page 42). The following may be taken as mean values of C with corresponding values of K_0:

For inward projecting entrance,	$C = 0.75$, $K_0 = 0.78$.
For sharp-cornered entrance	$C = 0.82$, $K_0 = 0.50$.
For slightly rounded entrance	$C = 0.90$, $K_0 = 0.23$.
For bell-mouth entrance	$C = 0.98$, $K_0 = 0.04$.

For convenience of reference the above values of K_0 are repeated in Table 55, page 171. Table 54, page 170, gives values of lost head at entrance to pipes corresponding to velocities of from 2 to 30 feet per second

Loss of Head Due to Friction

By far the most important consideration in connection with the flow of water in pipes is the determination of the proper allowance for friction between the moving water and the inner surface of the pipe. In the case of long pipes, this loss may so far exceed the combined effect of all other losses as to make the consideration of the latter unnecessary. All losses should be investigated, however, and especially those due to poor alignment either horizontally or vertically (see loss of head due to bends, page 168).

An investigation of the loss of head due to friction in pipes must necessarily be based upon experimental rather than theoretical considerations. A large number of experiments on different kinds of pipe have been performed during the past century, the results of which are now available in a more or less satisfactory form. It is unfortunate that these experiments present many apparent inconsistencies.

The fact that the existing experimental data, which have been taken with great care and usually under favorable conditions, give conflicting results emphasizes the fact that the engineer in practice is apt to get results equally conflicting and difficult to explain.

The one thing that the engineer should be warned against is the danger of accepting blindly a formula which gives average results, without first assuring himself that his conditions are average conditions. Before selecting a formula for a given problem the engineer should have some knowledge of the dis-

crepancies in the experimental data on which the formula is based in order that he may understand the possible error attached to his result. It should also be remembered that designing a pipe too small to discharge a given quantity of water may lead to serious inconvenience if not financial loss, while a pipe of slightly larger diameter which provides the required capacity may not add materially to the cost. The engineer should therefore know the worst condition as well as the average and best conditions to be expected in solving all pipe problems.

It has been quite generally accepted that the loss of head due to friction in a straight pipe of uniform diameter, free from obstructions, varies with the roughness of the inner surface of the pipe, directly as the length of the pipe, and as some power of the diameter and velocity of water.

The formula which, until the last few years, has been used almost exclusively is the Chezy formula, usually written for pipes, in the form

$$H_1 = f\frac{l}{d}\cdot\frac{v^2}{2g} \tag{12}$$

H_1 being the friction head, l the length of pipe and d the diameter of pipe, all expressed in feet; v is the velocity of water in feet per second, and f is an empirical coefficient which varies with the roughness of the pipe and also with v and d.

The ideal formula would evidently express H_1 as a function of l, d and v with a coefficient depending for its value solely on the degree of roughness of the pipe. This coefficient should then be constant for all pipes constructed of the same material. Many attempts to devise such a formula have been made, but with indifferent success. Most of the more recent investigations have been based upon the so-called exponential formula written in the form

$$H_1 = K\frac{l}{d^n}\cdot v^m \tag{13}$$

K being the coefficient which varies with the roughness of the pipe and m and n being constant exponents.

It may readily be seen by logarithmically plotting experimental results for different pipes that m is not a constant, but apparently increases with the degree of roughness of the pipe, being as low as 1.74 for very smooth pipes and as high as 2.08 in cases of extreme roughness. A value of 1.25 for n appears

to fit quite satisfactorily all experimental results and this value has been quite generally accepted.

Common Formulas for Friction Loss in Pipes

Before proceeding with the discussion of this subject the more commonly used formulas for loss of head due to friction in pipes are here introduced. The following nomenclature will be used:

l = Length of pipe in feet.
H_1 = Loss of head due to friction in length l in feet.
H_f = Loss of head due to friction in 1000 feet of pipe.
d = Diameter of pipe in feet.
v = Mean velocity of water in feet per second.
r = Mean hydraulic radius $= \frac{d}{4}$.
s = Mean slope of hydraulic gradient in distance considered $= \frac{H_1}{l}$.
f, K_1, K, K', and c = Empirical coefficients.
m, and n = Empirical exponents.

The Chezy formula

$$H_1 = f\,\frac{l}{d}\,\frac{v^2}{2g} \tag{12}$$

which has been extensively used for cast-iron pipes, is being replaced by other formulas: f varies with both v and d. Fanning's values of f for straight smooth pipes, which have been commonly used, are given in Table 56, page 171. As originally published Fanning's coefficients are one-fourth of the values given in Table 56 since he uses r in place of d in the above formula. In this form Fanning's formula, with the accompanying table of coefficients, is intended to apply to smooth open channels as well as pipes. Several formulas for determining f, which is expressed as a function of v or d, have been used in the past. Among these may be mentioned the formulas of D'Aubisson, Weisbach and Darcy. Later investigations have shown, however, that since f varies with both v and d the Chezy formula can best be used in connection with a table.

The Williams and Hazen formula, expressed in the nomenclature given above, is

$$H_1 = K\,\frac{lv^{1.87}}{d^{1.25}} \tag{14}$$

K ranges from 0.00028 to 0.00048 with an average value of 0.00038 for ordinary clean pipes. For rough tuberculated pipes K may become as high as 0.00070.

Tutton's formulas proposed[1] in 1899 for the discharge of pipes constructed of different materials are as follows:

For new cast-iron pipes, and pipes of similar degree of roughness

$$v = cr^{0.66} s^{0.51} \qquad c = 126 \text{ to } 158 \tag{15a}$$

For cast-iron pipes slightly tuberculated or with mud deposits

$$v = cr^{0.66} s^{0.51} \qquad c = 87 \text{ to } 132 \tag{15b}$$

For cast-iron pipes heavily tuberculated

$$v = cr^{0.66} s^{0.51} \qquad c = 30 \text{ to } 85 \tag{15c}$$

For new asphalt-coated pipes

$$v = cr^{0.62} s^{0.55} \qquad c = 175 \tag{15d}$$

For old asphalt-coated pipes

$$v = cr^{0.66} s^{0.51} \qquad c = 80 \text{ to } 140 \tag{15e}$$

For wood stave pipes

$$v = cr^{0.66} s^{0.51} \qquad c = 129 \tag{15f}$$

For new tar- or asphalt-coated lap-riveted pipes

$$v = cr^{0.66} s^{0.51} \qquad c = 125 \text{ to } 135 \tag{15g}$$

For old tar- or asphalt-coated lap-riveted pipes

$$v = cr^{0.66} s^{0.51} \qquad c = 110 \text{ to } 114 \tag{15h}$$

Unwin's Formula.—After a careful study of the available experimental data on the flow of water in iron pipes, Unwin[2] adopted the base formula

$$H_1 = K' \frac{l}{d^n} \frac{v^m}{2g} \tag{16}$$

and prepared the following table of values of K', m and n to be substituted in the formula.

Kind of pipe	K'	m	n
Wrought-iron	.0226	1.75	1.210
Asphalted-iron	.0254	1.85	1.127
Riveted wrought-iron	.0260	1.87	1.390
New cast-iron	.0215	1.95	1.168
Cleaned cast-iron	.0243	2.00	1.168
Incrusted cast-iron	.0440	2.00	1.160

[1] C. H. Tutton; The Flow of Water in Pipes. *Journal Association of Engineering Societies*, 1899, vol. 23, p. 151.

[2] W. C. Unwin; A Treatise on Hydraulics, p. 217.

Moritz and Scobey Formulas for Wood Stave Pipes.—Moritz in 1911 published[1] the results of an investigation of wood stave pipe based upon a study of experiments by himself and other experiments available at that time. This investigation included experiments on pipes of diameters varying from 4 to 55¾ inches. Moritz derived formulas for loss of head, velocity, and discharge which are given below.

Scobey in 1916 published[2] the results of a very thorough investigation on wood stave pipe. Scobey offered a new set of formulas "based upon all experiments on round stave pipe known to him from description in engineering literature," and supplemented by an extensive set of experiments in which he was aided by Ernest C. Fortier. Scobey's formula which is given below represents within an error of ⅔ of 1 per cent. the mean of all the experiments, the maximum divergence for individual experiments being about 30 per cent. plus and minus.

The Moritz formulas for wood stave pipes are

$$H_f = 0.38 \frac{v^{1.8}}{d^{1.26}} \tag{17a}$$

$$v = 1.72 d^{0.7} \ H_f^{0.555} \tag{17b}$$

$$Q = 1.35 d^{2.7} \ H_f^{0.555} \tag{17c}$$

The Scobey formulas for wood stave pipes are

$$H_f = 0.419 \frac{v^{1.8}}{d^{1.17}} \tag{18a}$$

$$v = 1.62 d^{0.65} \ H_f^{0.555} \tag{18b}$$

$$Q = 1.272 d^{2.65} \ H_f^{0.555} \tag{18c}$$

Barnes' Formulas.—In 1916 Barnes published[3] the results of a very comprehensive investigation of the available experiments on friction in pipes and open channels. As a result of this investigation new formulas were developed for a number of different kinds of pipe. In each case the formula for new clean pipe is given together with a percentage to be added to Q to allow for deterioration. These formulas are as follows:

[1] E. A. Moritz: Flow of Water in Wood Stave Pipes. *Trans.* Amer. Soc. Civ. Eng., vol. 74, p. 411.

[2] Fred C. Scobey: The Flow of Water in Wood Stave Pipe. *Bulletin* No. 376, U. S. Department of Agriculture.

[3] A. A. Barnes; Hydraulic Flow Reviewed, Spon and Chamberlain Publishers.

For new asphalted cast-iron pipes. For purposes of design 45 per cent. to be added to Q to allow for deterioration.

$$v = 174.1\, r^{0.769}\, s^{0.529} \quad \text{or} \quad H_1 = 0.000436 \frac{lv^{1.891}}{d^{1.454}} \tag{19a}$$

For new uncoated cast-iron pipes. Add 55 per cent. to Q to allow for deterioration.

$$v = 136.6\, r^{0.600}\, s^{0.512} \quad \text{or} \quad H_1 = 0.000343 \frac{lv^{1.953}}{d^{1.172}} \tag{19b}$$

For new asphalted screw-jointed riveted wrought-iron pipes. Add 33 per cent. to Q to allow for deterioration.

$$v = 190.2\, r^{0.608}\, s^{0.557} \quad \text{or} \quad H_1 = 0.000368 \frac{lv^{1.795}}{d^{1.092}} \tag{19c}$$

For new asphalted single-riveted wrought-iron and steel pipes. Add 33 per cent. to Q to allow for deterioration.

$$v = 171.4\, r^{0.723}\, s^{0.527} \quad \text{or} \quad H_1 = 0.000386 \frac{lv^{1.898}}{d^{1.372}} \tag{19d}$$

For new asphalted double-riveted wrought-iron and steel pipes. Add 33 per cent. to Q to allow for deterioration.

$$v = 129.9\, r^{0.440}\, s^{0.520} \quad \text{or} \quad H_1 = 0.000279 \frac{lv^{1.923}}{d^{0.846}} \tag{19e}$$

For clean lead pipes. Add 5 per cent. to Q to allow for deterioration.

$$v = 232.8 r^{0.679}\, s^{0.591} \quad \text{or} \quad H_1 = 0.000486 \frac{lv^{1.692}}{d^{1.149}} \tag{9f}$$

For clean glass pipes. Add 5 per cent. to Q to allow for deterioration.

$$v = 143.0\, r^{0.562}\, s^{0.556} \quad \text{or} \quad H_1 = 0.000539 \frac{lv^{1.799}}{d^{1.011}} \tag{19g}$$

For new smooth wood stave pipes. Add 8 per cent. to Q to allow for deterioration.

$$v = 223.3 r^{0.660}\, s^{0.586} \quad \text{or} \quad H_1 = 0.000467 \frac{lv^{1.707}}{d^{1.126}} \tag{19h}$$

For new unplaned wood stave pipes. Add 8 per cent. to Q to allow for deterioration.

$$v = 182.5 r^{0.666}\, s^{0.569} \quad \text{or} \quad H_1 = 0.000540 \frac{lv^{1.757}}{d^{1.171}} \tag{19i}$$

For neat cement pipes. Add 6 per cent. to Q to allow for deterioration.

$$v = 136.3r^{0.635}\ s^{0.484} \quad \text{or} \quad H_1 = 0.000240\ \frac{lv^{2.066}}{d^{1.312}} \qquad (19j)$$

Formulas Advocated

The author has adopted the method, suggested by F. C. Lea, of selecting formulas in pairs of the form

$$H_1 = K\frac{l}{d^{1.25}} \cdot v^m \qquad (20)$$

which cover the upper and lower ranges of experimental data for each kind of pipe. The general formula to express the loss of head due to friction in pipes has been taken as

$$H_1 = K_1\frac{l}{d^{1.25}} \cdot \frac{v^2}{2g} \qquad (21)$$

Since the exponent of v has been shown to vary for different kinds of pipe, it seems simpler to assume for it a constant value of 2 and to prepare a table of values of K_1 varying with the roughness of the pipe and velocity of water but not varying with d.

From equations (20) and (21) the following relation between K_1 and v may be obtained:

$$K_1 = \frac{2gK}{v^{2-m}} \qquad (22)$$

The following equations are recommended by the author as expressing approximately the upper and lower limits of experimental values for the classes of pipes named. The first five equations which are given by Lea,[1] have been verified by a careful examination of practically all of the available experimental data pertaining to the subject. The last two formulas have been computed by the author and are based upon what are apparently the most reliable available data.[2]

[1] F. C. Lea: Hydraulics, p. 138.

[2] C. D. Marx and C. B. Wing: Experiments on Flow of Water in 6-Foot Steel and Wood Pipe Line at Ogden, Utah. *Trans.* Amer. Soc. Civ. Eng., vols. 40 and 44.

T. A. Noble: Flow of Water in Wood Pipes. *Trans.* Amer. Soc. Civ. Eng., vol. 49.

E. A. Moritz: Experiments on the Flow of Water in Wood Stave Pipes. *Trans.* Amer. Soc. Civ. Eng., vol. 74.

H. D. Newell: Studies of the Coefficient of Friction in Reinforced-Concrete Pipe. *Engineering News*, May 1, 1913.

Fred C. Scobey: The Flow of Water in Wood Stave Pipe. *Bulletin* No. 376, U. S. Department of Agriculture.

For clean cast-iron pipes:

$$H_1 = .00029\,\frac{lv^{1.80}}{d^{1.25}} \text{ to } .00042\,\frac{lv^{1.97}}{d^{1.25}};\ \text{mean } H_1 = .00036\,\frac{lv^{1.93}}{d^{1.25}} \qquad (23a)$$

For old cast-iron pipes:

$$H_1 = .00047\,\frac{lv^{1.94}}{d^{1.25}} \text{ to } .00069\,\frac{lv^{2.04}}{d^{1.25}};\ \text{mean } H_1 = .00060\,\frac{lv^{2}}{d^{1.25}} \qquad (23b)$$

For clean riveted pipes:

$$H_1 = .00040\,\frac{lv^{1.93}}{d^{1.25}} \text{ to } .00054\,\frac{lv^{2.08}}{d^{1.25}};\ \text{mean } H_1 = .00050\,\frac{lv^{2}}{d^{1.25}} \qquad (23c)$$

For galvanized pipes:

$$H_1 = .00035\,\frac{lv^{1.80}}{d^{1.25}} \text{ to } .00045\,\frac{lv^{1.96}}{d^{1.25}};\ \text{mean } H_1 = .00040\,\frac{lv^{1.88}}{d^{1.25}} \qquad (23d)$$

For smooth asphalted pipes:

$$H_1 = .00030\,\frac{v^{1.76}}{d^{1.25}} \text{ to } .00038\,\frac{lv^{1.81}}{d^{1.25}};\ \text{mean } H_1 = .00034\,\frac{lv^{1.78}}{d^{1.25}} \qquad (23e)$$

For clean wooden pipes:

$$H_1 = .00037\,\frac{lv^{1.74}}{d^{1.25}} \text{ to } .00053\,\frac{lv^{1.81}}{d^{1.25}};\ \text{mean } H_1 = .00045\,\frac{lv^{1.77}}{d^{1.25}} \qquad (23f)$$

For concrete pipes:

$$H_1 = .00040\,\frac{lv^{1.75}}{d^{1.25}} \text{ to } .00068\,\frac{lv^{2.00}}{d^{1.25}};\ \text{mean } H_1 = .00050\,\frac{lv^{1.85}}{d^{1.25}} \qquad (23g)$$

Practically all of the experimental results for the kinds of pipe listed lie between the first two values of H_1 as given in the above formulas. The last values of H_1 represent the approximate means of the experiments. Table 57, page 172, gives values of K_1 to be used in the formula

$$H_1 = K_1\,\frac{l}{d^{1.25}} \cdot \frac{v^2}{2g} \qquad (21)$$

which were computed from formula (22), the values of K and m being taken from formulas 23a to 23g inclusive. Tables 60 and 61, pages 175 and 178, giving values of $\frac{1}{d^{1.25}}$, with d expressed in feet or inches will assist in solving formula (21).

It will be observed that Table 57 leaves considerable discretion in choosing the value of K_1. There will always be an element of uncertainty in this choice and care in making the selection to correspond to the conditions is essential if any degree of accuracy is to be expected. In general, to use the lower values of K_1 the pipe should be of good quality, each section should be carefully laid to grade and placed in true alignment, and the pipe should be well maintained and kept clean. If jointed pipes are used, a smooth surface should be obtained at the joints. With only ordinary care in these regards the higher values will be safer.

The values of K_1 given in Table 57 do not include all kinds nor conditions of pipe. The list of pipes given, however, is about as extensive as the available experimental data warrant. When it is remembered that, other things being equal, the value of K_1 depends only upon the degree of roughness of the pipe it should not be difficult to decide to which class the pipe in question belongs or which class it more closely resembles.

The amount of allowance necessary for deterioration may be difficult to decide. The carrying capacity of wooden and concrete pipes changes little with age. There is a tendency for deposits to form on the inner surface of iron and steel pipes which results both in increasing the roughness of the surface and in decreasing the effective diameter of the pipe. Such deposits usually take the form of hemispheres not exceeding 1 to 1½ inches in diameter. The effect of deposits is more noticeable on pipes of small diameter, which in extreme cases may be entirely blocked.

The deterioration of iron and steel pipes is greatly retarded by a good coating of bitumen or pitch. The effectiveness of the coating depends upon the quality of the material used and the care taken to place it in smooth even layers. Only the uncoated portions of such pipes will be incrusted to any great extent, though a very minute hole may form the nucleus of a deposit.

The method suggested by Barnes (pages 156 to 158) of adding a certain percentage to Q to allow for deterioration has advantages. In some ways it would appear more consistent to apply a correction to the diameter of the pipe, since the effect of corrosion is to reduce the effective diameter. It is doubtful, however, whether the more common method of considering the deterioration in selecting the coefficient is not equally satisfactory.

Discussion of Pipe Formulas

The modern tendency is undoubtedly to express friction loss in pipes by the general formula

$$H_1 = K \frac{l}{d^n} v^m \qquad (20)$$

In this form the formula has the advantage of simplicity and at the same time it appears to conform to the laws of flow as indicated by the available experiments as well as any formula

that has yet been suggested. In the latter regard it unquestionably possesses advantages over the Chezy formula.

The general plan of procedure has been to select the experiments for pipes of a certain class and by means of logarithmic plotting to determine the values of K, m and n which best represent the mean of the experiments used. Such formulas manifestly give results which at the best correspond only to the means of experimental values. In studying any particular set of experiments it will usually be found that several values of the above constants may be selected which appear to fit the experiments equally well. This fact accounts for the large number of pipe formulas of this type which have been promulgated during the past few years. Every investigator has found that many of the experimental results when plotted fall far from the mean position which may be expressed by any formula.

Probably the most successful attempt to classify and correlate the available pipe experiments and to deduce from them mean working formulas is that of Barnes (page 156). This investigation has evidently been conducted with great care and thoroughness and the resulting formulas show a remarkably close agreement with the greater portion of the experiments. It does not appear quite clear however why the flow through pipes quite similar in character should apparently follow widely varying laws as indicated by the divergence in exponents selected. As an example it may be noted that Barnes chooses an exponent for d of 1.372 for single-riveted pipes and decides that the addition of another row of rivets changes the value of this exponent to 0.846.

The wide divergence in experimental results cannot be explained on the grounds of experimental error. Experiments which have been performed with great care and under favorable conditions frequently fall far from the mean values determined from other experiments. It therefore appears that there is danger in definitely accepting any formula or group of formulas designed to give mean values. In using the formulas expressing the approximate upper and lower ranges of experimental values, or the general formula (formula (21)) with values of K_1 determined from these formulas, the engineer can readily see the limiting results which have been obtained and use his discretion in selecting what appears to be the most reasonable or safest value, basing his decision on the particular conditions involved in the problem.

Though a list of mean values of K_1 is included in Table 57 the author is opposed to using them indiscriminately. The engineer should, by a careful study of conditions and a knowledge of the kind of pipe to be used and class of workmanship to be insisted upon, be able to estimate a coefficient for each individual case.

Solution of Pipe Formulas

Formula (21) (page 158) is sufficient for the solution of any pipe problem involving only the loss of head due to friction. For convenience this formula is here repeated, the nomenclature being that given on page 154.

$$H_1 = K_1 \frac{l}{d^{1.25}} \cdot \frac{v^2}{2g} \tag{21}$$

The length of pipe, or length corresponding to a given loss of head, is always given. There are three general types of problems:

1. To determine the friction head; the diameter of pipe and velocity or discharge being given.

Solution.—H_1 may be obtained directly from formula (21), with the assistance of the tables. K_1 is given in Table 57, page 172. Values of $\frac{1}{d^{1.25}}$ may be taken from the second column of Table 60, page 175, or Table 61, page 178. Values of $\frac{v^2}{2g}$ are given in Tables 19 and 20, pages 51 and 53. If preferred, the head lost in 1000 feet of pipe 1 foot in diameter may be taken from Table 59, page 174, and Tables 60 and 61 may be used to reduce this loss of head to any other diameter. For any other length of pipe multiply the above result by the length in feet divided by 1000.

2. To determine the discharge or velocity; the diameter and friction head being given.

Solution.—Formula (21) may be used by first assuming a velocity and choosing a value of K_1, corresponding to the assumed velocity, from Table 57, $\frac{1}{d^{1.25}}$ being taken from Table 60 or 61 as before. After solving for v a new value of K_1 may be selected from Table 57, and v may be determined again in the same manner. If the second value of v differs greatly from the first value, the equation may be solved a third time, though two solutions are usually sufficient.

Equation (21) may be transposed to the form

$$v = \sqrt{\frac{2g}{K_1} \cdot \frac{H_1}{l}} \cdot d^{0.625}$$

or putting $\sqrt{\frac{2g}{K_1}} = c_1$ and $\frac{H_1}{l} = s$ the formula becomes

$$v = c_1\, s^{1/2}\, d^{0.625} \tag{21a}$$

This form of the equation may in some cases be more convenient than formula (21). Table 58, page 173, gives c_1 for different values of v and the third columns of Tables 60 and 61 give $d^{0.625}$ with d expressed in either feet or inches. The same general method must be followed in solving problems by formula (21a) as by formula (21). c_1 must be first assumed, then v may be computed, and a new value of c_1 chosen to correspond to this value of v when the formula may again be solved for a closer value of v. In the same manner a third value of v may be computed if necessary.

If the discharge of the pipe is required it may be obtained from the relation,

$$Q = Av$$

A being the area of the pipe in square feet. Values of A corresponding to diameters of pipes expressed in feet and inches respectively are given in the fourth columns of Tables 60 and 61, pages 175 and 178.

3. To determine the diameter; the friction head and discharge being given.

Solution.—Formula (21) may be applied directly but the solution will be somewhat complicated. Formula (21) may be transposed to the form

$$d = 0.496 \left(\frac{K_1 Q^2 l}{H_1}\right)^{1/5.25} \tag{21b}$$

The solution of formula (21b) is given in the first and fifth columns of Tables 60 and 61, pages 175 and 178. Intermediate values of d not given in these tables may be interpolated to the nearest 0.01 foot or 1/8 inch.

Formula (21b) must be solved by successive approximations. A value of v is first assumed and K_1 is taken from Table 57, page 172. Then d may be determined with the aid of table 60 or 61 by computing $\frac{K_1 Q^2 l}{H_1}$ and selecting from column 1

the value of d corresponding to the value of $\frac{K_1Q^2l}{H_1}$ given in column 5. The corresponding cross-sectional area of the pipe is given in column 4. From the relation $v = \frac{Q}{A}$ the approximate velocity may be determined and a new value of K_1 may be selected from Table 57. A new value of d may now be computed in the same manner as before.

The above process should be repeated until the computed value of d does not differ sufficiently from the assumed d to affect appreciably the value of K_1. Usually two solutions are sufficient.

Other Losses in Pipes

In the complete solution of a pipe problem it may be necessary to consider the velocity head and losses of head other than H_1, the loss due to friction. As already set forth (pages, 150 and 151) the total head is represented by the equation

$$H = \frac{v^2}{2g} + H_0 + H_1 + H_2 + H_3 + H_4 + H_5 \qquad (7)$$

which may also be written

$$H = \frac{v^2}{2g} + K_0\frac{v^2}{2g} + K_1\frac{l}{d^{1.25}}\cdot\frac{v^2}{2g} + K_2\frac{v^2}{2g} + K_3\frac{v^2}{2g} + K_4\frac{v^2}{2g} + K_5\frac{v^2}{2g} \quad (8)$$

In the above formulas $\frac{v^2}{2g}$, H_0, H_1, H_2, etc., and K_0, K_1, K_2, K_3, etc., vary with the velocity. Problems in which the velocity and diameter and length of pipe are given to determine the total head, H, may be solved directly from formulas (7) and (8). Other problems, in which v is unknown, must be solved by a method of approximations. Since the loss from friction, H_1, in nearly all cases greatly exceeds all other losses, it is usual to make a first solution of the problem by neglecting all losses except H_1, and thus obtain an approximate value of v to be used in formulas (7) or (8). Successive solutions should be made until the computed value of v does not differ sufficiently from the v used in the solution to appreciably affect the head losses or the values of the coefficients used.

The method of obtaining K_0 and K_1 have already been explained, together with the use of tables of values of these coefficients. The determination of values of K_2, K_3, K_4 and K_5 will now be taken up in order.

Loss of Head Due to Sudden and Gradual Enlargements.—Borda has investigated this matter theoretically and found that the loss in pipes due to *sudden enlargement* may be represented by the formula

$$H_2 = \frac{(v_1 - v_2)^2}{2g} \tag{25}$$

in which H_2 is the lost head and v_1 and v_2 the velocities in the smaller and larger pipes respectively.

This loss has also been investigated experimentally by Baer,[1] Brightmore,[2] Archer[3] and others. These experiments are fairly concordant and show that Borda's theoretical formula gives values of H_2 too small for the lower velocities and smaller differences in diameter of the two pipes and too large for the opposite conditions. Many combinations of pipes were used, in the experiments, between the approximate limits of 1.5 inches and 6 inches in diameter. The maximum velocity in the smaller pipe in any of the experiments was about 30 feet per second.

As a result of his experiments, Archer deduced the formula

$$H_2 = 1.098\frac{(v_1 - v_2)^{1.919}}{2g} = 0.01705(v_1 - v_2)^{1.919} \tag{26}$$

This formula appears to be as satisfactory as any yet suggested. It does not hold in the limit when the area of the larger pipe becomes infinite, and the total velocity head is evidently lost. In such cases the formula gives values of H_2 slightly greater than $\frac{v^2}{2g}$ for velocities below 3 feet per second, from which point it gradually decreases with the velocity, to about 80 per cent. of $\frac{v^2}{2g}$ for a velocity of 40 feet per second.

Table 62, page 181, gives values of H_2 for velocities up to 40 feet per second with the ratio of the diameter of the larger pipe to the diameter of the smaller pipe varying from 1.2 to infinity. This table was computed by formula (26) for ratios

[1] *Dingler's Journal*, March 23, 1907.

[2] *Proc.* Inst. of Civ. Eng., vol. 169, p. 323.

[3] W. H. Archer: Loss of Head Due to Enlargements in Pipes. *Trans.* Amer. Soc. Civ. Eng., vol. 76, pp. 999–1026.

of 3 or less, and for ratios from 4 to infinity, the values given were interpolated graphically between values from formula (26) for ratio 3 and the total velocity head for ratio infinity. Table 63, page 181, gives a corresponding table of K_2 for use in the formula

$$H_2 = K_2\frac{v^2}{2g} \tag{27}$$

Losses due to gradual enlargement have been investigated by Parker[1] from a study of experiments by Andres, Gibson and others. The formula suggested by Andres for a conical enlargement may be written:

$$H_2 = f\frac{v_1^2 - v_2^2}{2g} \tag{28}$$

in which v_1 and v_2 are velocities in smaller and larger pipes respectively and f is an empirical coefficient depending for its value upon the angle θ between the sides of the pipe (θ = double the angle between the axis of the pipe and its side).

Andres gives values of f for smaller values of θ and Gibson for values up to 90°. Their results are not entirely consistent, but the author has used them to plot a mean curve giving the results of Andres more weight for the smaller angles. The following are results obtained in this manner:

θ	2°	3°	4°	5°	6°	7°	8°	9°	10°	11°	12°
f	.033	.036	.039	.042	.046	.050	.055	.066	.078	.090	.100

θ	15°	20°	25°	30°	35°	40°	45°	50°	60°	75°	90°
f	.16	.31	.40	.49	.55	.60	.64	.67	.72	.72	.67

Using the above values of f, Table 64, page 182, which gives K_2 in the formula

$$H_2 = K_2\frac{v^2}{2g} \tag{27}$$

has been prepared. v is the velocity in the smaller pipe. It will not be practicable to give a table of values of H_2, for gradual enlargement, as H_2 in this case varies with three functions—the angle of the cone, the ratio of diameter of two pipes, and the velocity.

Loss of Head Due to Contractions.—Merriman[2] suggests the

[1] Philip A. Morley Parker: The Control of Water, pp. 796–800.

[2] Mansfield Merriman: Treatise on Hydraulics, p. 183.

following formula for determining the loss of head due to sudden contraction:

$$H_3 = \left(\frac{1}{c} - 1\right)^2 \frac{v^2}{2g} \tag{29}$$

in which v is the velocity in the smaller pipe and

$$c = 0.582 + \frac{0.0418}{1.1 - r} \tag{30}$$

r being the ratio of diameters of the two pipes.

Brightmore[1] experimented on pipes 6 inches in diameter contracted to 4 inches and 3 inches, the mean of his results being represented approximately by the formula

$$H_3 = \frac{0.7(v_1 - v_2)^2}{2g} \tag{31}$$

Parker[2] suggests that formula (29) be used for higher velocities when the head lost is 1 foot or more while formula (31) is more reliable for smaller losses of head.

Following the above suggestion the author computed H_3 by both formulas for various velocities and diameter ratios. The results were then plotted and curves drawn through the points by gradually changing from results obtained by formula (31) for lower velocities to formula (29) for higher velocities. Values of H_3 taken from these curves are given in Table 65, page 182. Corresponding values of K_3 for determining loss of head due to sudden contraction in the formula

$$H_3 = K_3 \frac{v^2}{2g} \tag{32}$$

are given in Table 66, page 183, v being the velocity in the smaller pipe.

Loss of Head Due to Obstructions.—The most common obstructions in pipes are valves when partially open, though the following analysis should apply approximately to any obstructions. The basic formula chosen is

$$H_4 = K_4 \frac{v^2}{2g} \tag{33}$$

in which H_4 is the loss of head due to the obstruction, K_4 is an empirical coefficient, and v is the mean velocity of water in the pipe. Experiments indicate that K_4 varies with the amount of obstruction but it does not appear to vary appreciably with the velocity.

[1] *Proc.* Inst. Civ. Eng., vol. 169, p. 323.

[2] PHILIP A. MORLEY PARKER: The Control of Water, pp. 796–800.

Parker[1] has correlated experiments by Smith, Kuichling and Weisbach, the results of which are fairly concordant. The author has plotted all of these experiments graphically and drawn a mean curve through them. Values of K_4 taken from this curve, for different ratios of area of pipe to area at obstruction, are given in Table 68, page 184. Table 67, page 184, gives corresponding values of lost head, H_4, for different velocities.

Loss of Head Due to Bends.—The loss of head due to bends in pipes is considered as the excess loss over what would occur in a straight pipe of the same material and equal length. It is probable that the roughness of the pipe has some effect upon this loss of head but present data are not sufficient to show to what extent this is the case. It is usual to consider the loss due to bends for all kinds of pipes, to be a function of the velocity and radius of the bend.

Most investigators have considered that the loss of head varies with the radius of the bend expressed in pipe diameters. In what appears, however, to be a very satisfactory analysis of the experiments bearing on this subject, Fuller[2] shows that a closer agreement with available experimental data may be obtained by considering the lost head for pipes of all diameters to be a function of the radius of the center line of the pipe without regard to its diameter. Fuller gives the formula

$$H_5 = cv^{2.25} \tag{34}$$

in which H_5 is the lost head in feet for bends of 90°, v is the velocity in feet per second, and c is a coefficient varying with the radius of the center line of the pipe. Fuller gives a curve of values of c for different radii up to 60 feet, from which the following table was prepared.

Radius in feet	c	Radius in feet	c	Radius in feet	c	Radius in feet	c	Radius in feet	c
0.00	.01350	2	.00243	6	.00230	15	.00478	40	.00750
0.25	.00600	3	.00239	7	.00242	20	.00597	50	.00803
0.50	.00400	4	.00236	8	.00271	25	.00656	60	.00860
1.00	.00275	5	.00233	10	.00335	30	.00695		

[1] Philip A. Morley Parker: The Control of Water, p. 787.

[2] W. E. Fuller: Loss of Head in Bends. *Journal of New England Water Works Association*, December, 1913.

Table 69, page 185, giving loss of head in 90° bends for different radii and velocities, was computed from formula (34) using values of c contained in the above table. Table 70, page 186, gives corresponding values of K_5 to use in the formula

$$H_5 = K_5 \frac{v^2}{2g} \tag{35}$$

For bends less than 90° Fuller gives the following approximate rules:

For loss of head due to 45° bends use three-fourths that due to 90° bends of the same radius.

For loss of head due to 22.5° bends use one-half that due to 90° bends of the same radius.

For loss of head due to a Y branch, use three-fourths that due to a tee (zero radius).

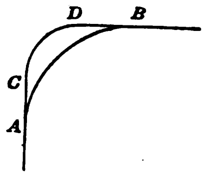


FIG. 62.

It appears from Tables 69 and 70 that a minimum loss of head occurs for radii of from 4 to 7 feet. In designing a pipe line, however, it may be found that the total loss of head in the pipe line between two given points will be less by using a curve of greater radius due to shortening the length of the pipe. This may be seen from Fig. 62. Assuming that the radius of the bend CD is from 4 to 7 feet, the radius giving the minimum excess loss of head, the bend AB having a greater radius than CD, the total loss of head in the pipe AB may be less than the total loss of head in the pipe $ACDB$ because of its shorter length.

Critical Velocity

Under the conditions discussed in the preceding pages the flow of water in pipes has been considered turbulent, and the loss of head due to friction was found to vary as v^n, n ranging from about 1.7 to 2.1. This law, however, does not apply to very small pipes nor very low velocities. In such cases there is a velocity, called the *critical velocity*, below which stream-line flow exists and the loss of head due to friction varies directly as v.

There appear to be two points of critical velocity; the lower critical velocity being the velocity below which stream-line flow always exists and the higher critical velocity being the velocity above which turbulent flow always exists. Between the two critical velocities the flow may be either stream-line or turbulent.

Our knowledge on this subject is based largely upon experiments by Reynolds,[1] the results of which are summarized in the equations given below. If v_c is the lower critical velocity, v_d the higher critical velocity, T the temperature of the water in degrees Centigrade, and d the diameter of the pipe in feet

$$v_c = \frac{0.0388}{d(1 + 0.0336T + 0.000221T^2)} \tag{36}$$

and

$$v_d = \frac{0.2458}{d(1 + 0.0336T + 0.000221T^2)} \tag{37}$$

Table 71, page 187, gives the lower critical velocities for different temperatures and diameters of pipes computed from formula (36) and Table 72, page 187, gives the corresponding higher critical velocities computed from formula (37). The values contained in these tables must be considered as only rough approximations as they are based upon a limited range of experiments, and Barnes and Coker[2] have produced stream-line motion at velocities 50 per cent. greater than are given by formula (37).

If v' be the velocity (below the critical velocity) in feet per second, d_i the diameter of the pipe in inches, h the friction head in feet, l the length of pipe in feet, and T the temperature of water in degrees Centigrade, the velocity in a pipe, where stream-line flow exists, is given by the following formula by Reynolds:

$$v' = \frac{361d_i^2h}{l}(1 + 0.0337T + 0.000221T^2) \tag{38}$$

It will be noted from Tables 71 and 72 that critical velocities occur below the velocities in which the engineer is usually interested.

TABLE 54.—LOSS OF HEAD, H_0, AT ENTRANCE TO PIPES

Condition at entrance	Velocity in feet per second														
	2	3	4	5	6	7	8	10	12	14	16	18	20	25	30
Inward-projecting	.05	.11	.19	.30	.44	.59	.78	1.21	1.75	2.38	3.10	3.93	4.85	7.58	10.91
Sharp-cornered	.03	.07	.12	.19	.28	.38	.50	.78	1.12	1.52	1.99	2.52	3.11	4.86	7.00
Slightly rounded	.01	.03	.06	.09	.13	.18	.23	.36	.51	.70	.92	1.16	1.43	2.24	3.22
Bell-mouth	.00	.01	.01	.02	.02	.03	.04	.06	.09	.12	.16	.20	.25	.39	.50

[1] *Phil. Trans.* Royal Society, 1882 and 1895.

[2] H. T. BARNES and E. G. COKER: The Flow of Water through Pipes. *Proc.* Royal Society of London, 1905.

TABLE 55.—VALUES OF K_0 FOR DETERMINING LOSS OF HEAD AT ENTRANCE TO PIPES FROM THE FORMULA $H_0 = K_0\frac{v^2}{2g}$

Condition at entrance	K_0
Inward-projecting pipe	.78
Sharp-cornered	.50
Slightly rounded	.23
Bell-mouth	.04

TABLE 56.—VALUES OF f IN THE CHEZY FORMULA $H_1 = f\frac{l}{d}\cdot\frac{v^2}{2g}$ AS DETERMINED BY FANNING, FOR STRAIGHT SMOOTH PIPES

Diameter of pipe in inches	Mean velocity (v) in feet per second								
	0.5	1.0	2.0	3.0	4.0	5.0	10.0	15.0	20.0
0.5	.0418	.0381	.0340	.0317	.0300	.0287	.0250	.0237	.0231
0.75	.0405	.0366	.0329	.0308	.0292	.0280	.0247	.0235	.0229
1.	.0398	.0353	.0317	.0300	.0285	.0274	.0245	.0234	.0228
1.5	.0384	.0343	.0310	.0292	.0278	.0268	.0241	.0231	.0226
2.	.0364	.0330	.0301	.0284	.0272	.0263	.0237	.0228	.0223
3.	.0354	.0317	.0288	.0273	.0263	.0254	.0232	.0224	.0219
4.	.0340	.0306	.0279	.0265	.0255	.0247	.0226	.0219	.0214
5.	.0328	.0297	.0271	.0258	.0249	.0241	.0222	.0215	.0211
6.	.0317	.0289	.0264	.0252	.0243	.0236	.0219	.0212	.0208
8.	.0296	.0275	.0253	.0242	.0234	.0227	.0212	.0207	.0202
10.	.0283	.0262	.0242	.0232	.0225	.0220	.0206	.0201	.0197
12.	.0268	.0250	.0233	.0224	.0218	.0213	.0201	.0196	.0192
14.	.0256	.0241	.0225	.0217	.0211	.0207	.0196	.0192	.0188
16.	.0244	.0232	.0218	.0210	.0205	.0201	.0192	.0188	.0184
18.	.0236	.0224	.0211	.0204	.0199	.0196	.0188	.0183	.0181
20.	.0229	.0216	.0204	.0198	.0194	.0191	.0184	.0180	.0177
24.	.0212	.0202	.0193	.0187	.0184	.0182	.0176	.0173	.0170
30.	.0194	.0186	.0179	.0175	.0173	.0171	.0166	.0163	.0161
36.	.0177	.0171	.0166	.0164	.0162	.0161	.0156	.0154	.0152
42.	.0164	.0160	.0156	.0154	.0153	.0152	.0148	.0146	.0145
48.	.0153	.0150	.0147	.0146	.0145	.0144	.0141	.0139	.0138
54.	.0144	.0142	.0140	.0138	.0137	.0137	.0134	.0133	.0132
60.	.0137	.0135	.0133	.0132	.0131	.0131	.0128	.0127	.0125
72.	.0126	.0124	.0122	.0120	.0120	.0119	.0117	.0117	.0117
84.	.0117	.0115	.0113	.0112	.0112	.0111	.0109	.0109	.0108

TABLE 57.—VALUES OF K_1 FOR DETERMINING THE LOSS OF HEAD (IN FEET) DUE TO FRICTION IN PIPES FROM THE FORMULA $H_1 = K_1 \frac{l}{d^{1.25}} \cdot \frac{v^2}{2g}$. IN THIS FORMULA l = LENGTH OF PIPE IN FEET AND d = DIAMETER OF PIPE IN FEET. VALUES OF $\frac{1}{d^{1.25}}$ FOR DIFFERENT DIAMETERS OF PIPE ARE GIVEN IN TABLES 60 AND 61

Velocity	Clean cast-iron pipe			Old cast-iron pipe			Clean riveted pipe			Galvanised pipe			Smooth asphalted pipe			Clean wooden pipe			Concrete pipe		
	From	To	Mean	From	To	Mean	From	To	Mean	From	To	Mean	From	To	Mean	From	To	Mean	From	To	Mean
0.5	.022	.028	.024	.082	.043	.038	.027	.033	.032	.026	.030	.028	.023	.028	.025	.028	.040	.034	.031	.044	.036
1.	.019	.027	.023	.030	.044	.038	.026	.035	.032	.023	.029	.026	.019	.025	.022	.024	.034	.029	.026	.044	.032
2.	.017	.026	.021	.029	.046	.038	.025	.037	.032	.020	.028	.024	.016	.022	.019	.020	.030	.025	.022	.044	.029
3.	.015	.026	.020	.029	.047	.038	.024	.038	.032	.018	.028	.023	.015	.020	.017	.018	.028	.023	.020	.044	.027
4.	.014	.026	.020	.028	.047	.038	.023	.040	.032	.017	.027	.022	.014	.019	.016	.017	.026	.021	.018	.044	.026
5.	.014	.026	.019	.028	.048	.038	.023	.040	.032	.016	.027	.021	.013	.018	.015	.016	.025	.020	.017	.044	.025
6.	.013	.026	.019	.027	.048	.038	.023	.040	.032	.016	.027	.021	.013	.017	.015	.015	.024	.019	.016	.044	.025
8.	.012	.025	.018	.027	.048	.038	.022	.041	.032	.015	.027	.020	.012	.016	.014	.014	.023	.018	.015	.044	.024
10.	.012	.025	.018	.027	.049	.038	.022	.042	.032	.014	.026	.020	.011	.016	.013	.013	.022	.017	.014	.044	.023
15.	.011	.025	.017	.026	.050	.038	.021	.043	.032	.013	.026	.019	.010	.015	.012	.012	.020	.016	.013	.044	.022
20.	.010	.025	.016	.026	.050	.038	.021	.044	.032	.012	.026	.018	.009	.014	.011	.011	.019	.015	.012	.044	.021
25.	.010	.025	.016	.025	.051	.038	.021	.045	.032	.012	.026	.018	.009	.013	.011	.010	.018	.014	.012	.044	.020
30.	.010	.024	.015	.025	.051	.038	.020	.046	.032	.011	.025	.018	.009	.013	.010	.010	.018	.013	.011	.044	.019
40.	.009	.024	.015	.024	.052	.038	.020	.047	.032	.011	.025	.017	.008	.012	.010	.009	.017	.012	.010	.044	.019

TABLE 58.—VALUES OF c_1 IN THE FORMULA $v = c_1 s^{1/2} d^{0.625}$. IN THIS FORMULA $s = \frac{H_1}{l}$ AND d = DIAMETER OF PIPE IN FEET. VALUES OF $d^{0.625}$ ARE GIVEN IN TABLES 60 AND 61. SQUARE ROOTS OF DECIMAL NUMBERS ARE GIVEN IN TABLE 83

Velocity	Clean cast-iron pipe			Old cast-iron pipe			Clean riveted pipe			Galvanized pipe			Smooth asphalted pipe			Clean wooden pipe			Concrete pipe		
	From	To	Mean	From	To	Mean	From	To	Mean	From	To	Mean	From	To	Mean	From	To	Mean	From	To	Mean
0.5	54.8	48.3	51	45.0	38.6	42	48.8	44.3	45	49.9	46.5	48	53.2	48.0	50	47.6	40.7	44	45.9	38.3	43
1.	58.8	48.9	53	46.0	38.1	42	50.0	43.0	45	53.5	47.1	50	57.8	51.3	54	52.1	43.5	47	50.0	38.3	45
2.	62.9	49.4	55	46.9	37.5	42	51.2	41.9	45	57.4	47.8	52	62.9	54.8	59	56.9	46.4	51	54.5	38.3	47
3.	65.5	49.7	56	47.5	37.2	42	51.9	41.2	45	59.8	48.2	53	66.0	56.9	61	60.0	48.3	53	57.4	38.3	49
4.	67.4	49.9	57	47.9	37.0	42	52.5	40.7	45	61.6	48.5	54	68.3	58.4	63	62.3	49.6	55	59.5	38.3	50
5.	68.8	50.1	58	48.2	36.8	42	52.8	40.3	45	62.9	48.7	55	70.2	59.7	65	64.1	50.7	57	61.0	38.3	51
6.	70.1	50.2	59	48.5	36.7	42	53.2	40.1	45	64.1	48.9	56	71.5	60.9	66	65.6	51.6	58	62.5	38.3	51
8.	72.1	50.4	60	49.0	36.5	42	53.8	39.6	45	66.0	49.1	57	74.2	62.5	68	68.1	53.1	60	64.7	38.3	52
10.	73.3	50.6	61	49.2	36.4	42	54.2	39.3	45	67.4	49.4	57	76.2	63.9	70	70.4	54.1	62	66.7	38.3	53
15.	76.2	50.9	62	49.9	36.1	42	54.9	38.6	45	70.2	49.8	59	79.9	66.4	73	73.9	56.2	64	70.2	38.3	55
20.	79.1	51.1	63	50.3	35.8	42	55.6	38.2	45	72.1	50.1	60	82.8	68.3	75	76.9	57.8	66	72.7	38.3	56
25.	81.1	51.3	64	50.6	35.7	42	55.9	37.8	45	73.9	50.3	60	85.1	69.6	77	79.1	59.0	68	74.6	38.3	57
30.	82.4	51.4	65	50.9	35.6	42	56.4	37.6	45	75.2	50.5	61	86.6	70.7	79	81.1	60.2	70	76.5	38.3	58
40.	84.6	51.6	66	51.4	35.4	42	56.9	37.2	45	77.2	50.8	62	89.8	72.7	82	84.2	61.8	72	79.1	38.3	59
50.	86.6	51.8	67	51.7	35.2	42	57.4	36.8	45	79.1	51.0	63	92.1	74.6	84	86.6	63.1	74	81.5	38.3	60

TABLE 59.—LOSS OF HEAD DUE TO FRICTION IN 1000 FEET OF STRAIGHT PIPE FOR A DIAMETER OF 1 FOOT. TO DETERMINE THE FRICTION HEAD LOST PER 1000 FEET OF PIPE OF ANY OTHER DIAMETER, MULTIPLY THE VALUES IN THIS TABLE BY $\frac{1}{d^{1.25}}$. VALUES OF $\frac{1}{d^{1.25}}$ ARE GIVEN IN TABLES 60 AND 61

Velocity	Clean cast-iron pipe		Old cast-iron pipe		Clean riveted pipe		Galvanized pipe		Smooth asphalted pipe		Clean wooden pipe		Concrete pipe	
	From	To	From	To	From	To	From	To	From	To	From	To	From	To
0.5	.09	.11	.12	.17	.11	.13	.10	.12	.09	.11	.11	.15	.12	.17
1.	.29	.42	.47	.69	.40	.54	.35	.45	.30	.38	.37	.53	.40	.68
2.	1.03	1.64	1.82	2.85	1.53	2.29	1.22	1.75	1.01	1.34	1.24	1.86	1.35	2.74
3.	2.11	3.65	4.00	6.50	3.34	5.32	2.52	3.88	2.07	2.78	2.50	3.86	2.74	6.16
4.	3.56	6.44	6.98	11.68	5.82	9.68	4.23	6.81	3.43	4.70	4.13	6.52	4.53	10.94
5.	5.33	10.00	10.76	18.45	8.98	15.40	6.34	10.58	5.09	7.04	6.10	9.76	6.73	17.10
6.	7.4	14.3	15.3	26.8	12.8	22.5	8.8	15.1	7.1	9.8	8.4	13.6	9.2	24.6
7.	9.8	19.4	20.7	36.6	17.2	31.0	11.6	20.5	9.3	12.9	11.0	17.9	12.2	33.5
8.	12.3	25.3	26.8	48.1	22.2	40.9	14.7	26.6	11.6	16.4	13.8	22.8	15.3	43.8
9.	15.4	31.9	33.7	61.2	27.8	52.2	18.3	33.4	14.4	20.3	16.9	28.3	18.8	55.4
10.	18.7	39.2	41.4	75.9	34.1	65.0	22.1	41.1	17.3	24.6	20.2	34.2	22.6	68.4
11.	22.2	47.3	49.8	92.2	41.0	79.2	26.3	49.5	20.4	29.3	24.0	40.7	26.7	82.8
12.	26.0	56.2	58.9	110.1	48.6	95.0	30.7	58.7	23.7	34.3	28.0	47.5	31.1	98.6
13.	30.0	65.7	68.8	129.5	56.7	112.0	35.5	68.6	27.3	39.6	32.3	55.0	35.8	115.5
14.	34.1	76.1	79.3	150.6	65.5	130.8	40.5	79.4	31.3	45.2	36.7	63.0	40.7	134.0
15.	38.5	87.1	90.6	173.4	74.9	151.0	45.8	90.9	35.3	51.1	41.3	71.4	45.8	153.9
16.	43.	99.	103.	198.	85.	173.	52.	103.	40.	57.	46.	80.	51.	175.
17.	48.	112.	115.	224.	95.	196.	58.	116.	44.	64.	51.	90.	57.	198.
18.	54.	125.	128.	252.	106.	221.	64.	130.	49.	71.	57.	99.	63.	222.
19.	59.	139.	143.	282.	118.	247.	70.	145.	54.	78.	62.	110.	70.	247.
20.	65.	154.	159.	312.	130.	275.	77.	160.	58.	86.	68.	120.	76.	274.
21.	71.	169.	175.	345.	143.	304.	84.	176.	64.	94.	74.	131.	83.	302.
22.	77	185.	191.	379.	156.	335.	92.	193.	69.	102.	80.	143.	90.	331.
23.	83.	202.	208.	415.	170.	367.	99.	210.	75.	111.	87.	155.	97.	362.
24.	89.	220.	226.	452.	185.	401.	107.	229.	81.	120.	93.	167.	105.	394.
25.	95.	240.	245.	492.	200.	437.	115.	248.	87.	129.	100.	180.	113.	428.

TABLE 60.—TO ASSIST IN SOLVING PIPE PROBLEMS. DIAMETER IN FEET WITH CORRESPONDING VALUES OF $\frac{1}{d^{1.25}}$, $d^{0.625}$, AREAS OF CIRCLES, AND VALUES OF $\frac{K_1Q^2l}{H_1}$ CORRESPONDING TO d IN THE FORMULA,

$$d = 0.496\left(\frac{K_1Q^2l}{H_1}\right)^{\frac{1}{5.25}}$$

Diameter in feet	$\frac{1}{d^{1.25}}$ (feet)	$d^{0.625}$ (feet)	Area in square feet	$\frac{K_1Q^2l}{H_1}$	Diameter in feet	$\frac{1}{d^{1.25}}$ (ft.)	$d^{0.625}$ (feet)	Area in square feet	$\frac{K_1Q^2l}{H_1}$
0.05	42.295	.1538	.0020	.000006					
0.06	33.675	.1723	.0028	.000015	1.50	.602	1.288	1.767	333.5
0.07	27.773	.1898	.0038	.000035	1.55	.578	1.315	1.887	396.2
0.08	23.504	.2063	.0050	.000069	1.60	.556	1.341	2.011	468.0
0.09	20.286	.2220	.0064	.000128	1.65	.535	1.367	2.138	550.1
0.10	17.783	.2371	.0079	.000223	1.70	.515	1.393	2.270	643.5
0.12	14.159	.2657	.0113	.00058	1.75	.497	1.419	2.405	749.2
0.14	11.677	.2926	.0154	.00131	1.80	.480	1.444	2.545	868.6
0.16	9.882	.3181	.0201	.00263	1.85	.464	1.469	2.688	1,003.
0.18	8.529	.3423	.0255	.00489	1.90	.448	1.493	2.835	1,154.
0.20	7.477	.3657	.0314	.00850	1.95	.434	1.517	2.986	1,322.
0.25	5.657	.4205	.0491	.0274	2.00	.420	1.541	3.142	1,510.
0.30	4.504	.4712	.0707	.0714	2.05	.408	1.565	3.301	1,719.
0.35	3.715	.5188	.0962	.1600	2.10	.396	1.590	3.464	1,951.
0.40	3.144	.5640	.1257	.3230	2.15	.384	1.614	3.631	2,208.
0.45	2.713	.6071	.1590	.6000	2.20	.373	1.637	3.801	2,491.
0.50	2.378	.6485	.1963	1.043	2.25	.363	1.660	3.976	2,803.
0.55	2.111	.6883	.2376	1.720	2.30	.353	1.683	4.155	3,146.
0.60	1.894	.7266	.2827	2.716	2.35	.344	1.706	4.337	3,522.
0.65	1.713	.7640	.3318	4.135	2.40	.335	1.728	4.524	3,933.
0.70	1.562	.8001	.3848	6.101	2.45	.326	1.751	4.714	4,383.
0.75	1.433	.8353	.4418	8.764	2.50	.318	1.773	4.909	4,874.
0.80	1.322	.8697	.5027	12.300	2.55	.310	1.795	5.107	5,408.
0.85	1.225	.9035	.5675	16.910	2.60	.303	1.817	5.309	5,988.
0.90	1.141	.9362	.6362	22.830	2.65	.296	1.839	5.515	6,618.
0.95	1.066	.9686	.7088	30.320	2.70	.289	1.861	5.726	7,300.
1.00	1.000	1.000	.785	39.69	2.75	.282	1.883	5.940	8,038.
1.05	.941	1.031	.866	51.28	2.80	.276	1.904	6.158	8,836.
1.10	.888	1.061	.950	65.46	2.85	.270	1.925	6.379	9,696.
1.15	.840	1.091	1.039	82.67	2.90	.264	1.946	6.605	10,620.
1.20	.796	1.121	1.131	103.40	2.95	.258	1.967	6.835	11,620.
1.25	.756	1.150	1.227	128.1	3.00	.253	1.987	7.069	12,690.
1.30	.720	1.178	1.327	157.4	3.05	.248	2.008	7.306	13,840.
1.35	.687	1.206	1.431	191.8	3.10	.243	2.028	7.548	15,080.
1.40	.657	1.234	1.539	232.2	3.15	.238	2.049	7.793	16,400.
1.45	.628	1.261	1.651	279.2	3.20	.234	2.069	8.042	17,810.

TABLE 60 (*Continued*)

TO ASSIST IN SOLVING PIPE PROBLEMS. DIAMETER IN FEET WITH CORRESPONDING VALUES OF $\frac{1}{d^{1.25}}$, $d^{0.625}$, AREAS OF CIRCLES, AND VALUES OF $\frac{K_1Q^2l}{H_1}$ CORRESPONDING TO d IN THE FORMULA,

$$d = 0.496 \left(\frac{K_1Q^2l}{H_1}\right)^{\frac{1}{5.25}}$$

Diameter in feet	$\frac{1}{d^{1.25}}$ (feet)	$d^{0.625}$ (feet)	Area in square feet	$\frac{K_1Q^2l}{H_1}$	Diameter in feet	$\frac{1}{d^{1.25}}$ (feet)	$d^{0.625}$ (feet)	Area in square feet	$\frac{K_1Q^2l}{H_1}$
3.25	.2291	2.089	8.296	19,320	5.00	.1337	2.735	19.63	185,500
3.30	.2248	2.109	8.553	20,930	5.05	.1321	2.752	20.03	195,400
3.35	.2206	2.129	8.814	22,650	5.10	.1305	2.769	20.43	205,800
3.40	.2166	2.149	9.079	24,490	5.15	.1289	2.786	20.83	216,600
3.45	.2127	2.169	9.348	26,440	5.20	.1274	2.803	21.24	227,900
3.50	.2089	2.188	9.621	28,510	5.25	.1259	2.820	21.65	239,600
3.55	.2052	2.208	9.898	30,720	5.30	.1244	2.836	22.06	251,800
3.60	.2017	2.227	10.18	33,060	5.35	.1229	2.853	22.48	264,500
3.65	.1982	2.246	10.46	35,540	5.40	.1215	2.869	22.90	277,800
3.70	.1949	2.265	10.75	38,170	5.45	.1201	2.886	23.33	291,600
3.75	.1917	2.284	11.04	40,960	5.50	.1187	2.903	23.76	305,900
3.80	.1885	2.303	11.34	43,910	5.55	.1174	2.919	24.19	320,800
3.85	.1854	2.322	11.64	47,030	5.60	.1161	2.935	24.63	336,200
3.90	.1825	2.341	11.95	50,320	5.65	.1148	2.951	25.07	352,300
3.95	.1796	2.360	12.25	53,800	5.70	.1135	2.967	25.52	369,000
4.00	.1768	2.378	12.57	57,480	5.75	.1123	2.984	25.97	386,300
4.05	.1741	2.397	12.88	61,350	5.80	.1111	3.000	26.42	404,300
4.10	.1714	2.415	13.20	65,430	5.85	.1099	3.017	26.88	422,900
4.15	.1688	2.434	13.53	69,730	5.90	.1087	3.033	27.34	442,200
4.20	.1663	2.452	13.85	74,250	5.95	.1076	3.049	27.81	462,300
4.25	.1639	2.470	14.19	79,020	6.00	.1065	3.065	28.27	483,000
4.30	.1615	2.488	14.52	84,020	6.05	.1054	3.081	28.75	504,500
4.35	.1592	2.507	14.86	89,280	6.10	.1043	3.096	29.22	526,800
4.40	.1569	2.525	15.21	94,790	6.15	.1032	3.112	29.71	549,900
4.45	.1547	2.543	15.55	100,590	6.20	.1022	3.128	30.19	573,800
4.50	.1526	2.560	15.90	106,660	6.25	.1012	3.144	30.68	598,500
4.55	.1505	2.578	16.26	113,040	6.30	.1002	3.160	31.17	624,000
4.60	.1484	2.596	16.62	119,720	6.35	.0992	3.176	31.67	650,400
4.65	.1464	2.614	16.98	126,700	6.40	.0982	3.191	32.17	677,800
4.70	.1445	2.631	17.35	134,030	6.45	.0972	3.207	32.67	706,100
4.75	.1426	2.648	17.72	141,670	6.50	.0963	3.222	33.18	735,300
4.80	.1408	2.665	18.10	149,680	6.55	.0954	3.238	33.70	765,500
4.85	.1390	2.683	18.47	158,050	6.60	.0945	3.253	34.21	796,600
4.90	.1372	2.700	18.86	166,800	6.65	.0936	3.268	34.73	828,800
4.95	.1354	2.718	19.24	175,940	6.70	.0927	3.283	35.26	862,000

TABLE 60 (*Concluded*)

TO ASSIST IN SOLVING PIPE PROBLEMS. DIAMETER IN FEET WITH CORRESPONDING VALUES OF $\frac{1}{d^{1.25}}$, $d^{0.625}$, AREAS OF CIRCLES, AND VALUES OF $\frac{K_1Q^2l}{H_1}$ CORRESPONDING TO d IN THE FORMULA,

$$d = 0.496\left(\frac{K_1Q^2l}{H_1}\right)^{\frac{1}{5.25}}$$

Diameter in feet	$\frac{1}{d^{1.25}}$ (feet)	$d^{0.625}$ (feet)	Area in square feet	$\frac{K_1Q^2l}{H_1}$	Diameter in feet	$\frac{1}{d^{1.25}}$ (feet)	$d^{0.625}$ (feet)	Area in square feet	$\frac{K_1Q^2l}{H_1}$
6.75	.0918	3.299	35.78	896,300	8.50	.0689	3.810	56.75	3,007,000
6.80	.0910	3.314	36.32	931,800	8.55	.0684	3.824	57.41	3,101,000
6.85	.0902	3.329	36.85	968,400	8.60	.0679	3.838	58.09	3,197,000
6.90	.0894	3.344	37.39	1,006,000	8.65	.0674	3.852	58.77	3,296,000
6.95	.0886	3.360	37.94	1,044,900	8.70	.0669	3.866	59.45	3,397,000
7.00	.0878	3.375	38.48	1,085,000	8.75	.0664	3.880	60.13	3,501,000
7.05	.0871	3.390	39.04	1,126,000	8.80	.0660	3.894	60.82	3,607,000
7.10	.0863	3.404	39.59	1,169,000	8.85	.0655	3.907	61.51	3,716,000
7.15	.0855	3.419	40.15	1,213,000	8.90	.0650	3.920	62.21	3,828,000
7.20	.0848	3.434	40.72	1,258,000	8.95	.0646	3.934	62.91	3,942,000
7.25	.0840	3.449	41.28	1,305,000	9.00	.0641	3.948	63.62	4,059,000
7.30	.0833	3.464	41.85	1,353,000	9.05	.0637	3.962	64.33	4,179,000
7.35	.0826	3.479	42.43	1,402,000	9.10	.0633	3.976	65.04	4,302,000
7.40	.0819	3.493	43.01	1,453,000	9.15	.0628	3.989	65.76	4,427,000
7.45	.0812	3.508	43.59	1,505,000	9.20	.0624	4.002	66.48	4,556,000
7.50	.0806	3.523	44.18	1,559,000	9.25	.0620	4.016	67.20	4,687,000
7.55	.0799	3.538	44.77	1,614,000	9.30	.0616	4.030	67.93	4,821,000
7.60	.0792	3.552	45.36	1,671,000	9.35	.0612	4.044	68.66	4,959,000
7.65	.0785	3.567	45.96	1,729,000	9.40	.0608	4.057	69.40	5,100,000
7.70	.0779	3.582	46.57	1,789,000	9.45	.0604	4.071	70.14	5,244,000
7.75	.0773	3.596	47.17	1,851,000	9.50	.0600	4.084	70.88	5,391,000
7.80	.0767	3.610	47.78	1,915,000	9.55	.0596	4.098	71.63	5,542,000
7.85	.0761	3.625	48.40	1,980,000	9.60	.0592	4.111	72.38	5,696,000
7.90	.0755	3.640	49.02	2,047,000	9.65	.0588	4.125	73.14	5,854,000
7.95	.0749	3.654	49.64	2,116,000	9.70	.0584	4.138	73.90	6,015,000
8.00	.0743	3.668	50.27	2,187,000	9.75	.0580	4.151	74.66	6,179,000
8.05	.0738	3.682	50.90	2,260,000	9.80	.0577	4.164	75.43	6,348,000
8.10	.0732	3.696	51.53	2,335,000	9.85	.0573	4.177	76.20	6,520,000
8.15	.0726	3.710	52.17	2,411,000	9.90	.0569	4.190	76.98	6,695,000
8.20	.0721	3.724	52.81	2,490,000	9.95	.0565	4.204	77.76	6,874,000
8.25	.0715	3.739	53.46	2,571,000	10.00	.0562	4.217	78.54	7,058,000
8.30	.0710	3.754	54.11	2,654,000					
8.35	.0704	3.768	54.76	2,739,000					
8.40	.0699	3.782	55.42	2,826,000					
8.45	.0694	3.796	56.08	2,915,000					

TABLE 61.—TO ASSIST IN SOLVING PIPE PROBLEMS. DIAMETER IN INCHES WITH CORRESPONDING VALUES OF $\frac{1}{d^{1.25}}$, $d^{0.625}$, AREAS OF CIRCLES, AND VALUES OF $\frac{K_1Q^2l}{H_1}$ CORRESPONDING TO d IN THE FORMULA,

$$d = 0.496\left(\frac{K_1Q^2l}{H_1}\right)^{\frac{1}{5.25}}$$

Diameter in inches	$\frac{1}{d^{1.25}}$ (feet)	$d^{0.625}$ (feet)	Area in square feet	$\frac{K_1Q^2l}{H_1}$	Diameter in inches	$\frac{1}{d^{1.25}}$ (ft.)	$d^{0.625}$ (feet)	Area in square feet	$\frac{K_1Q^2l}{H_1}$
¼	126.35	.0890	.0003	....	15½	.726	1.174	1.310	152.1
⅜	76.11	.1146	.0008	....	16	.698	1.197	1.396	179.7
½	53.12	.1372	.0014	.000002	16½	.672	1.220	1.485	211.2
¾	32.00	.1768	.0031	.000019	17	.647	1.243	1.576	247.0
1	22.39	.2113	.0055	.000087	17½	.624	1.266	1.670	287.7
1¼	16.87	.2434	.0085	.000276	18	.602	1.288	1.767	333.5
1½	13.45	.2727	.0123	.00072	18½	.582	1.311	1.867	385.1
1¾	11.10	.3001	.0167	.00162	19	.563	1.333	1.969	443.0
2	9.390	.3263	.0218	.00326	19½	.545	1.355	2.074	507.7
2½	7.105	.3751	.0341	.01050	20	.528	1.376	2.182	579.8
3	5.657	.4205	.0491	.0274	20½	.512	1.398	2.292	660.2
3½	4.665	.4630	.0668	.0616	21	.497	1.419	2.405	749.2
4	3.948	.5033	.0873	.1241	21½	.482	1.440	2.521	847.8
4½	3.408	.5417	.1104	.2303	22	.469	1.461	2.640	956.5
5	2.987	.5786	.1364	.4005	22½	.456	1.482	2.761	1,076.3
5½	2.652	.6141	.1650	.6605	23	.443	1.502	2.885	1,208.
6	2.378	.6485	.1963	1.0430	23½	.432	1.522	3.012	1,352.
6½	2.152	.6817	.2304	1.588	24	.420	1.542	3.142	1,510.
7	1.962	.7139	.2673	2.343	24½	.410	1.562	3.274	1,683.
7½	1.799	.7455	.3068	3.365	25	.400	1.582	3.409	1,872.
8	1.660	.7761	.3491	4.723	25½	.390	1.602	3.547	2,076.
8½	1.539	.8061	.3941	6.493	26	.380	1.621	3.687	2,299.
9	1.433	.8354	.4418	8.764	26½	.371	1.641	3.830	2,541.
9½	1.339	.8642	.4922	11.64	27	.363	1.660	3.976	2,803.
10	1.256	.8923	.5454	15.24	27½	.355	1.679	4.125	3,086.
10½	1.182	.9198	.6013	19.69	28	.347	1.698	4.276	3,392.
11	1.115	.9470	.6600	25.13	28½	.339	1.717	4.430	3,723.
11½	1.055	.9736	.7213	31.74	29	.332	1.736	4.587	4,079.
12	1.000	1.000	.7854	39.69	29½	.325	1.755	4.746	4,462.
12½	.950	1.026	.8522	49.16	30	.318	1.773	4.909	4,874.
13	.905	1.051	.9218	60.42	30½	.312	1.792	5.074	5,316.
13½	.863	1.076	.9940	73.66	31	.305	1.810	5.241	5,789.
14	.825	1.101	1.069	89.16	31½	.299	1.828	5.412	6,296.
14½	.789	1.126	1.147	107.35	32	.293	1.846	5.585	6,838.
15	.756	1.150	1.227	128.07	32½	.288	1.864	5.761	7,419.

TABLE 61 (*Continued*)

TO ASSIST IN SOLVING PIPE PROBLEMS. DIAMETER IN INCHES WITH CORRESPONDING VALUES OF $\frac{1}{d^{1.25}}$, $d^{0.625}$, AREAS OF CIRCLES, AND VALUES OF $\frac{K_1Q^2l}{H_1}$ CORRESPONDING TO d IN THE FORMULA, $d = 0.496\left(\frac{K_1Q^2l}{H_1}\right)^{\frac{1}{5.25}}$.

Diameter in inches	$\frac{1}{d^{1.25}}$ (feet)	$d^{0.625}$ (feet)	Area in square feet	$\frac{K_1Q^2l}{H_1}$	Diameter in inches	$\frac{1}{d^{1.25}}$ (feet)	$d^{0.625}$ (feet)	Area in square feet	$\frac{K_1Q^2l}{H_1}$
33	.2824	1.882	5.940	8,038	50½	.1659	2.455	13.91	75,030
33½	.2771	1.900	6.121	8,698	51	.1639	2.470	14.19	79,020
34	.2720	1.918	6.305	9,402	51½	.1619	2.485	14.47	83,170
34½	.2671	1.936	6.492	10,151	52	.1600	2.500	14.75	87,490
35	.2623	1.953	6.681	10,950	52½	.1581	2.515	15.03	92,010
35½	.2577	1.970	6.874	11,790	53	.1562	2.530	15.32	96,700
36	.2533	1.987	7.069	12,690	53½	.1544	2.545	15.61	101,580
36½	.2489	2.004	7.266	13,650	54	.1526	2.560	15.90	106,660
37	.2448	2.021	7.467	14,660	54½	.1508	2.575	16.20	111,960
37½	.2407	2.038	7.670	15,730	55	.1491	2.590	16.50	117,450
38	.2367	2.055	7.876	16,860	55½	.1474	2.605	16.80	123,200
38½	.2329	2.072	8.085	18,060	56	.1458	2.619	17.10	129,100
39	.2292	2.089	8.296	19,320	56½	.1442	2.634	17.41	135,300
39½	.2255	2.106	8.510	20,660	57	.1426	2.648	17.72	141,700
40	.2220	2.122	8.727	22,070	57½	.1410	2.663	18.03	148,300
40½	.2186	2.139	8.946	23,550	58	.1395	2.677	18.35	155,200
41	.2153	2.155	9.168	25,120	58½	.1380	2.692	18.67	162,400
41½	.2121	2.172	9.394	26,770	59	.1366	2.706	18.99	169,800
42	.2089	2.188	9.621	28,510	59½	.1351	2.720	19.31	177,500
42½	.2058	2.205	9.851	30,340	60	.1337	2.734	19.63	185,500
43	.2028	2.221	10.08	32,260	60½	.1323	2.749	19.96	193,700
43½	.1999	2.237	10.32	34,280	61	.1310	2.763	20.29	202,300
44	.1970	2.253	10.56	36,400	61½	.1297	2.777	20.63	211,100
44½	.1943	2.269	10.80	38,620	62	.1284	2.791	20.97	220,300
45	.1916	2.285	11.04	40,960	62½	.1271	2.805	21.31	229,800
45½	.1890	2.301	11.29	43,400	63	.1259	2.818	21.65	239,600
46	.1864	2.316	11.54	45,970	63½	.1246	2.832	21.99	249,800
46½	.1839	2.332	11.79	48,650	64	.1234	2.847	22.34	260,300
47	.1815	2.347	12.05	51,460	64½	.1222	2.861	22.69	271,100
47½	.1791	2.363	12.31	54,410	65	.1210	2.875	23.04	282,300
48	.1768	2.378	12.57	57,480	65½	.1198	2.889	23.40	293,900
48½	.1745	2.394	12.83	60,690	66	.1187	2.903	23.76	305,900
49	.1723	2.409	13.10	64,050	66½	.1176	2.917	24.12	318,300
49½	.1701	2.425	13.36	67,550	67	.1165	2.930	24.48	331,000
50	.1680	2.440	13.64	71,210	67½	.1154	2.944	24.85	344,200

TABLE 61 (*Concluded*)

TO ASSIST IN SOLVING PIPE PROBLEMS. DIAMETER IN INCHES WITH CORRESPONDING VALUES OF $\frac{1}{d^{1.25}}$, $d^{0.625}$, AREAS OF CIRCLES, AND VALUES OF $\frac{K_1Q^2l}{H_1}$ CORRESPONDING TO d IN THE FORMULA, $d = 0.496\left(\frac{K_1Q^2l}{H_1}\right)^{\frac{1}{5.25}}$

Diameter in inches	$\frac{1}{d^{1.25}}$ (feet)	$d^{0.625}$ (feet)	Area in square feet	$\frac{K_1Q^2l}{H_1}$	Diameter in inches	$\frac{1}{d^{1.25}}$ (feet)	$d^{0.625}$ (feet)	Area in square feet	$\frac{K_1Q^2l}{H_1}$
68	.1144	2.957	25.22	357,800	85½	.0859	3.413	39.87	1,191,000
68½	.1133	2.971	25.59	371,800	86	.0853	3.425	40.34	1,228,000
69	.1123	2.984	25.97	386,300	86½	.0847	3.438	40.81	1,266,000
69½	.1113	2.998	26.35	401,200	87	.0841	3.450	41.28	1,305,000
70	.1103	3.011	26.73	416,600	87½	.0835	3.462	41.76	1,344,000
70½	.1093	3.025	27.10	432,500	88	.0829	3.474	42.24	1,385,000
71	.1084	3.038	27.49	448,800	88½	.0823	3.486	42.72	1,427,000
71½	.1074	3.052	27.88	465,600	89	.0817	3.499	43.20	1,470,000
72	.1065	3.065	28.27	483,000	89½	.0811	3.511	43.69	1,514,000
72½	.1056	3.078	28.67	500,900	90	.0806	3.523	44.18	1,559,000
73	.1047	3.090	29.07	519,300	90½	.0800	3.535	44.67	1,605,000
73½	.1038	3.104	29.47	538,200	91	.0795	3.547	45.17	1,652,000
74	.1029	3.117	29.87	557,700	91½	.0789	3.560	45.66	1,700,000
74½	.1020	3.131	30.27	577,900	92	.0784	3.572	46.16	1,749,000
75	.1012	3.144	30.68	598,500	92½	.0779	3.584	46.67	1,799,000
75½	.1003	3.157	31.09	619,700	93	.0773	3.596	47.17	1,851,000
76	.0995	3.170	31.50	641,500	93½	.0768	3.608	47.68	1,904,000
76½	.0987	3.183	31.92	664,000	94	.0763	3.619	48.19	1,958,000
77	.0979	3.196	32.34	687,100	94½	.0758	3.632	48.71	2,013,000
77½	.0971	3.209	32.76	710,900	95	.0753	3.644	49.22	2,070,000
78	.0963	3.222	33.18	735,300	95½	.0748	3.656	49.74	2,128,000
78½	.0956	3.235	33.61	760,400	96	.0743	3.668	50.27	2,187,000
79	.0948	3.248	34.04	786,100	96½	.0738	3.680	50.79	2,247,000
79½	.0941	3.261	34.47	812,600	97	.0734	3.692	51.32	2,309,000
80	.0934	3.273	34.91	839,800	97½	.0729	3.704	51.85	2,372,000
80½	.0926	3.285	35.34	867,600	98	.0724	3.715	52.38	2,437,000
81	.0919	3.298	35.78	896,300	98½	.0719	3.727	52.92	2,503,000
81½	.0912	3.311	36.23	925,700	99	.0715	3.739	53.46	2,571,000
82	.0905	3.324	36.67	956,000	99½	.0710	3.751	54.00	2,640,000
82½	.0898	3.337	37.12	987,000	100	.0706	3.763	54.54	2,710,000
83	.0891	3.350	37.57	1,018,900					
83½	.0884	3.363	38.03	1,051,500					
84	.0878	3.375	38.48	1,084,900					
84½	.0871	3.388	38.94	1,119,400					
85	.0865	3.400	39.41	1,154,600					

TABLE 62.—LOSS OF HEAD (H_2) DUE TO SUDDEN ENLARGEMENT IN PIPES. $\frac{d_2}{d_1}$ = RATIO OF DIAMETER OF LARGER PIPE TO DIAMETER OF SMALLER PIPE. v = VELOCITY IN SMALLER PIPE

$\frac{d_2}{d_1}$	Velocity, v, in feet per second												
	2	3	4	5	6	7	8	10	12	15	20	30	40
1.2	.01	.01	.02	.04	.06	.07	.10	.14	.21	.32	.55	1.20	2.08
1.4	.02	.04	.06	.10	.14	.18	.23	.36	.51	.78	1.36	2.96	5.14
1.6	.02	.05	.09	.14	.20	.28	.36	.55	.78	1.19	2.07	4.50	7.82
1.8	.03	.07	.12	.18	.26	.35	.45	.70	.99	1.52	2.64	5.74	9.97
2.0	.04	.08	.14	.22	.31	.41	.53	.81	1.16	1.77	3.08	6.71	11.65
2.5	.05	.10	.17	.27	.38	.51	.66	1.01	1.44	2.20	3.83	8.34	14.48
3.0	.05	.11	.19	.30	.42	.57	.74	1.13	1.60	2.46	4.27	9.29	16.14
4.0	.06	.12	.22	.33	.47	.63	.82	1.26	1.79	2.75	4.78	10.44	18.15
5.0	.06	.13	.23	.35	.50	.67	.87	1.34	1.90	2.93	5.12	11.19	19.52
10.0	.06	.14	.24	.37	.54	.73	.95	1.47	2.11	3.27	5.75	12.69	22.31
∞	.06	.14	.25	.39	.56	.76	1.00	1.55	2.24	3.50	6.22	13.99	24.88

TABLE 63.—VALUES OF K_2 FOR DETERMINING LOSS OF HEAD DUE TO SUDDEN ENLARGEMENT IN PIPES FROM THE FORMULA $H_2 = K_2\frac{v^2}{2g}$. $\frac{d^2}{d_1}$ = RATIO OF LARGER PIPE TO SMALLER PIPE. v = VELOCITY IN SMALLER PIPE

$\frac{d_2}{d_1}$	Velocity, v, in feet per second												
	2	3	4	5	6	7	8	10	12	15	20	30	40
1.2	.11	.10	.10	.10	.10	.10	.10	.09	.09	.09	.09	.09	.08
1.4	.26	.26	.25	.24	.24	.24	.24	.23	.23	.22	.22	.21	.20
1.6	.40	.39	.38	.37	.37	.36	.36	.35	.35	.34	.33	.32	.32
1.8	.51	.49	.48	.47	.47	.46	.46	.45	.44	.43	.42	.41	.40
2.0	.60	.58	.56	.55	.55	.54	.53	.52	.52	.51	.50	.48	.47
2.5	.74	.72	.70	.69	.68	.67	.66	.65	.64	.63	.62	.60	.58
3.0	.83	.80	.78	.77	.76	.75	.74	.73	.72	.70	.69	.67	.65
4.0	.92	.89	.87	.85	.84	.83	.82	.81	.80	.79	.77	.75	.73
5.0	.96	.93	.91	.90	.89	.88	.87	.86	.85	.84	.82	.80	.78
10.0	.99	.98	.97	.96	.96	.96	.95	.95	.94	.94	.92	.91	.90
∞	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

TABLE 64.—VALUES OF K_2 FOR DETERMINING LOSS OF HEAD DUE TO GRADUAL ENLARGEMENTS IN PIPES FROM THE FORMULA $H_2 = K_2\frac{v^2}{2g}$. $\frac{d_2}{d_1}$ = RATIO OF DIAMETER OF LARGER PIPE TO DIAMETER OF SMALLER PIPE. ANGLE OF CONE IS TWICE THE ANGLE BETWEEN THE AXIS OF THE CONE AND ITS SIDE

$\frac{d_2}{d_1}$	Angle of cone													
	2°	4°	6°	8°	10°	15°	20°	25°	30°	35°	40°	45°	50°	60°
1.1	.01	.01	.01	.02	.03	.05	.10	.13	.16	.18	.19	.20	.21	.23
1.2	.02	.02	.02	.03	.04	.09	.16	.21	.25	.29	.31	.33	.35	.37
1.4	.02	.03	.03	.04	.06	.12	.23	.30	.36	.41	.44	.47	.50	.53
1.6	.03	.03	.04	.05	.07	.14	.26	.35	.42	.47	.51	.54	.57	.61
1.8	.03	.04	.04	.05	.07	.15	.28	.37	.44	.50	.54	.58	.61	.65
2.0	.03	.04	.04	.05	.07	.16	.29	.38	.46	.52	.56	.60	.63	.68
2.5	.03	.04	.04	.05	.08	.16	.30	.39	.48	.54	.58	.62	.65	.70
3.0	.03	.04	.04	.05	.08	.16	.31	.40	.48	.55	.59	.63	.66	.71
∞	.03	.04	.05	.06	.08	.16	.31	.40	.49	.56	.60	.64	.67	.72

TABLE 65.—LOSS OF HEAD (H_3) DUE TO SUDDEN CONTRACTIONS IN PIPES. $\frac{d_2}{d_1}$ = RATIO OF DIAMETER OF LARGER PIPE TO DIAMETER OF SMALLER PIPE. v = VELOCITY IN SMALLER PIPE

$\frac{d_2}{d_1}$	Velocity, v, in feet per second												
	2	3	4	5	6	7	8	10	12	15	20	30	40
1.1	.00	.00	.01	.01	.02	.03	.04	.06	.09	.15	.29	.75	1.49
1.2	.00	.01	.02	.03	.04	.06	.07	.12	.18	.28	.54	1.38	2.74
1.4	.01	.02	.04	.07	.10	.13	.17	.27	.40	.65	1.14	2.68	4.98
1.6	.02	.04	.06	.10	.14	.20	.26	.40	.67	.89	1.56	3.44	5.97
1.8	.02	.05	.08	.13	.19	.25	.33	.51	.73	1.12	1.92	4.05	6.72
2.0	.02	.05	.09	.14	.21	.28	.36	.55	.79	1.19	2.06	4.28	7.09
2.2	.02	.06	.10	.15	.22	.30	.38	.59	.84	1.28	2.20	4.56	7.41
2.5	.03	.06	.10	.16	.23	.31	.40	.62	.88	1.34	2.30	4.76	7.71
3.0	.03	.06	.11	.17	.24	.32	.42	.65	.92	1.40	2.41	4.98	8.11
4.0	.03	.06	.12	.18	.25	.34	.44	.69	.97	1.48	2.53	5.24	8.48
5.0	.03	.07	.12	.18	.26	.35	.46	.70	1.00	1.52	2.60	5.36	8.67
10.0	.03	.07	.12	.19	.27	.36	.47	.72	1.02	1.56	2.68	5.56	9.06
∞	.03	.07	.12	.19	.27	.36	.47	.72	1.03	1.58	2.71	5.68	9.36

TABLE 66.—VALUES OF K_3 FOR DETERMINING LOSS OF HEAD DUE TO SUDDEN CONTRACTION IN PIPES FROM THE FORMULA $H_3 = K_3 \frac{v^2}{2g}$. $\frac{d_2}{d_1}$ = RATIO OF DIAMETER OF LARGER PIPE TO DIAMETER OF SMALLER PIPE. v = VELOCITY IN SMALLER PIPE

$\frac{d_2}{d_1}$	Velocity, v, in feet per second												
	2	3	4	5	6	7	8	10	12	15	20	30	40
1.1	.03	.04	.04	.04	.04	.04	.04	.04	.04	.04	.05	.05	.06
1.2	.07	.07	.07	.07	.07	.07	.07	.08	.08	.08	.09	.10	.11
1.4	.17	.17	.17	.17	.17	.17	.17	.18	.18	.18	.18	.19	.20
1.6	.26	.26	.26	.26	.26	.26	.26	.26	.26	.25	.25	.25	.24
1.8	.34	.34	.34	.34	.34	.34	.33	.33	.32	.32	.31	.29	.27
2.0	.38	.38	.37	.37	.37	.37	.36	.36	.35	.34	.33	.31	.29
2.2	.40	.40	.40	.39	.39	.39	.39	.38	.37	.37	.35	.33	.30
2.5	.42	.42	.42	.41	.41	.41	.40	.40	.39	.38	.37	.34	.31
3.0	.44	.44	.44	.43	.43	.43	.42	.42	.41	.40	.39	.36	.33
4.0	.47	.46	.46	.46	.45	.45	.45	.44	.43	.42	.41	.37	.34
5.0	.48	.48	.47	.47	.47	.46	.46	.45	.45	.44	.42	.38	.35
10.0	.49	.48	.48	.48	.48	.47	.47	.46	.46	.45	.43	.40	.36
∞	.49	.49	.48	.48	.48	.47	.47	.47	.46	.45	.44	.41	.38

TABLE 67.—LOSS OF HEAD (H_4) DUE TO VALVES OR OBSTRUCTIONS IN PIPES. $\frac{A}{A_0}$ = RATIO OF AREA OF PIPE TO AREA OF OPENING IN OBSTRUCTION. v = VELOCITY OF WATER IN THE PIPE

$\frac{A}{A_0}$	Velocity, v, in feet per second												
	1	2	3	4	5	6	7	8	10	12	15	20	30
1.05	.00	.01	.01	.03	.04	.06	.08	.10	.15	.23	.36	.61	1.37
1.1	.00	.01	.03	.05	.07	.11	.15	.19	.30	.43	.67	1.20	2.70
1.2	.01	.03	.06	.10	.16	.24	.32	.42	.65	.94	1.47	2.61	5.88
1.4	.01	.06	.13	.24	.37	.54	.73	.95	1.49	2.14	3.35	5.95	13.35
1.6	.02	.10	.22	.38	.60	.86	1.17	1.53	2.39	3.44	5.38	9.56	21.52
1.8	.03	.13	.30	.54	.84	1.22	1.66	2.16	3.38	4.87	7.64	13.21	30.42
2.0	.04	.17	.38	.67	1.05	1.51	2.06	2.69	4.20	6.05	9.46	16.82	37.84
2.2	.05	.20	.46	.81	1.27	1.83	2.49	3.26	5.09	7.33	11.45	20.35	45.78
2.5	.06	.25	.56	1.00	1.56	2.24	3.05	3.98	6.23	8.97	14.01	24.91	56.05
3.0	.08	.31	.71	1.26	1.97	2.83	3.85	5.03	7.87	11.33	17.70	31.47	70.80
4.0	.10	.42	.94	1.68	2.62	3.78	5.14	6.71	10.49	15.10	23.60	41.95	94.40
5.0	.12	.50	1.12	1.99	3.11	4.48	6.10	7.97	12.46	17.94	28.02	49.82	112.10
6.0	.15	.58	1.31	2.33	3.64	5.25	7.14	9.33	14.58	20.99	32.79	58.30	131.18
7.0	.16	5	1.46	2.59	4.05	5.83	7.93	10.36	16.19	23.31	36.41	64.74	145.67
8.0	.18	1	1.59	2.82	4.41	6.35	8.64	11.28	17.63	25.39	39.66	70.51	158.65
9.0	.19	7	1.74	3.10	4.84	6.97	9.49	12.39	19.37	27.89	43.57	77.47	174.31
10.0	.21	.84	1.89	3.36	5.26	75.7	10.30	13.45	21.02	30.27	47.30	84.09	189.20

TABLE 68.—VALUES OF K_4 FOR DETERMINING LOSS OF HEAD DUE TO OBSTRUCTIONS IN PIPES FROM THE FORMULA $H_4 = K_4 \frac{v^2}{2g}$. $\frac{A_1}{A_0}$ = THE RATIO OF AREA OF PIPE TO AREA OF OPENING IN OBSTRUCTION

$\frac{A_1}{A_0}$	K_4	$\frac{A_1}{A_0}$	K_4	$\frac{A_1}{A_0}$	K_4
1.05	.10	2.0	2.70	6.0	9.4
1.1	.19	2.2	3.27	7.0	10.4
1.2	.42	2.5	4.00	8.0	11.3
1.4	.96	3.0	5.06	9.0	12.5
1.6	1.54	4.0	6.75	10.0	13.5
1.8	2.17	5.0	8.01		

TABLE 69.—LOSS OF HEAD, H_5, IN FEET, DUE TO 90° BENDS IN PIPES. R = THE RADIUS IN FEET OF THE CENTER LINE OF PIPE. V = VELOCITY OF WATER IN THE PIPE

R feet	Velocity, v, in feet per second												
	2	3	4	5	6	7	8	10	12	15	20	30	40
.0	.06	.16	.31	.50	.76	1.08	1.45	2.40	3.62	5.98	11.42	28.44	54.32
.25	.03	.07	.14	.22	.34	.48	.65	1.08	1.61	2.66	5.08	12.64	24.14
.50	.02	.05	.09	.15	.23	.32	.43	.71	1.07	1.77	3.38	8.43	16.09
1.	.01	.03	.06	.10	.16	.22	.30	.49	.74	1.22	2.33	5.79	11.07
2.	.01	.03	.06	.09	.14	.19	.26	.43	.65	1.08	2.06	5.12	9.78
3.	.01	.03	.05	.09	.14	.19	.26	.43	.64	1.06	2.02	5.03	9.62
4.	.01	.03	.05	.09	.13	.19	.25	.42	.63	1.05	2.00	4.97	9.50
5.	.01	.03	.05	.09	.13	.19	.25	.41	.63	1.03	1.97	4.91	9.38
6.	.01	.03	.05	.09	.13	.18	.25	.41	.62	1.02	1.95	4.85	9.26
7.	.01	.03	.06	.09	.14	.19	.26	.43	.65	1.07	2.05	5.10	9.74
8.	.01	.03	.06	.10	.15	.22	.29	.48	.73	1.20	2.29	5.71	10.91
10.	.02	.04	.08	.13	.19	.27	.36	.60	.90	1.48	2.83	7.06	13.48
15.	.02	.06	.11	.18	.27	.38	.52	.85	1.28	2.12	4.04	10.07	19.23
20.	.03	.07	.14	.22	.34	.48	.64	1.06	1.60	2.64	5.05	12.57	24.02
25.	.03	.08	.15	.25	.37	.52	.71	1.17	1.76	2.91	5.55	13.82	26.40
30.	.03	.08	.16	.26	.39	.55	.75	1.24	1.86	3.08	5.88	14.64	27.97
40.	.04	.09	.17	.28	.42	.60	.81	1.33	2.01	3.32	1.34	15.80	30.18
50.	.04	.10	.18	.30	.45	.64	.86	1.43	2.15	3.56	6.79	16.91	32.31
60.	.04	.10	.20	.32	.49	.69	.93	1.53	2.31	3.81	7.28	18.11	34.61

TABLE 70.—VALUES OF K_5 FOR DETERMINING THE LOSS OF HEAD DUE TO 90° BENDS IN PIPES FROM THE FORMULA $H_5 = K_5\frac{v^2}{2g}$. v = THE VELOCITY OF WATER IN THE PIPE, R = THE RADIUS OF THE CENTER LINE OF THE PIPE

R	Velocity, v, in feet per second												
	2	3	4	5	6	7	8	10	12	15	20	30	40
.0	1.03	1.14	1.23	1.30	1.36	1.42	1.46	1.54	1.62	1.71	1.84	2.03	2.18
.25	.46	.51	.55	.58	.60	.63	.65	.69	.72	.76	.82	.90	.97
.50	.31	.34	.36	.38	.40	.42	.43	.46	.49	.51	.54	.60	.65
1.	.21	.23	.25	.26	.28	.29	.30	.31	.33	.35	.37	.41	.44
2.	.19	.21	.22	.23	.24	.25	.26	.28	.29	.31	.33	.36	.39
3.	.18	.20	.22	.23	.24	.25	.26	.27	.29	.30	.33	.36	.39
4.	.18	.20	.21	.23	.23	.25	.26	.27	.28	.30	.32	.35	.38
5.	.18	.20	.21	.22	.23	.24	.25	.27	.28	.29	.32	.35	.38
6.	.18	.19	.21	.22	.23	.24	.25	.26	.28	.29	.31	.35	.37
7.	.19	.21	.22	.23	.24	.25	.26	.28	.29	.31	.33	.36	.39
8.	.21	.23	.25	.26	.27	.28	.29	.31	.32	.34	.37	.41	.44
10.	.26	.29	.31	.32	.34	.35	.36	.38	.40	.42	.46	.50	.54
15.	.37	.41	.43	.46	.48	.50	.52	.55	.57	.61	.65	.72	.77
20.	.45	.51	.54	.57	.60	.62	.64	.68	.72	.75	.81	.90	.97
25.	.50	.56	.59	.63	.65	.69	.71	.75	.79	.83	.89	.99	1.06
30.	.53	.58	.63	.67	.70	.73	.75	.79	.83	.88	.95	1.05	1.12
40.	.57	.64	.68	.72	.76	.79	.81	.86	.90	.95	1.02	1.13	1.21
50.	.61	.68	.73	.77	.81	.84	.87	.92	.96	1.02	1.08	1.21	1.30
60.	.66	.73	.78	.83	.87	.90	.93	.98	1.03	1.09	1.17	1.30	1.36

TABLE 71.—LOWER CRITICAL VELOCITIES COMPUTED FROM FORMULA (36) (Page 170)

Temperature		Diameter of pipe in inches									
Cent.	Fahr.	½	¾	1	1½	2	3	4	6	9	12
0	32	.93	.62	.47	.31	.23	.16	.12	.08	.05	.039
10	50	.69	.46	.34	.23	.17	.12	.09	.06	.04	.029
20	68	.53	.35	.26	.18	.13	.09	.07	.04	.03	.022
30	86	.42	.28	.21	.14	.11	.07	.05	.04	.02	.018
40	104	.35	.23	.17	.11	.09	.06	.04	.03	.02	.014
50	122	.29	.19	.14	.10	.07	.05	.04	.02	.02	.012
60	140	.24	.16	.12	.08	.06	.04	.03	.02	.01	.010
70	158	.21	.14	.10	.07	.05	.03	.03	.02	.01	.009
80	176	.18	.12	.09	.06	.05	.03	.02	.02	.01	.008
90	194	.16	.11	.08	.05	.04	.03	.02	.01	.01	.007
100	212	.14	.10	.07	.05	.04	.02	.02	.01	.01	.006

TABLE 72.—HIGHER CRITICAL VELOCITIES COMPUTED FROM FORMULA (37) (Page 170)

Temperature		Diameter of pipe in inches									
Cent.	Fahr.	½	¾	1	1½	2	3	4	6	9	12
0	32	5.89	3.93	2.95	1.97	1.47	.98	.74	.49	.33	.246
10	50	4.34	2.90	2.17	1.45	1.09	.72	.54	.36	.24	.181
20	68	3.35	2.23	1.68	1.12	.84	.56	.42	.28	.19	.140
30	86	2.67	1.78	1.34	.89	.67	.45	.33	.22	.15	.111
40	104	2.19	1.46	1.09	.73	.55	.36	.27	.16	.12	.091
50	122	1.83	1.22	.91	.61	.46	.30	.23	.15	.10	.076
60	140	1.55	1.03	.77	.52	.39	.26	.19	.13	.09	.064
70	158	1.33	.89	.66	.44	.33	.22	.17	.11	.07	.055
80	176	1.16	.77	.58	.39	.29	.19	.14	.10	.06	.048
90	194	1.01	.68	.51	.34	.25	.17	.13	.08	.06	.042
100	212	.90	.60	.45	.30	.22	.15	.11	.07	.05	.037

CHAPTER VII

FLOW OF WATER IN OPEN CHANNELS

The flow of water in open channels presents a problem even more complicated than the flow of water in pipes. This is due to a number of causes among which may be mentioned the great variety in shape and size of open conduits, variation in materials of which or through which the channels are constructed and difficulties of tabulating experimental data covering so wide a range of conditions. Theory offers little assistance in this connection and working formulas must be based largely upon the results of experimental investigation. Unfortunately the condition is still farther complicated by discrepancies and apparent inconsistencies in the available experimental data.

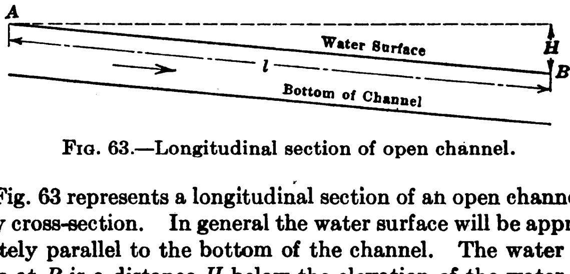


FIG. 63.—Longitudinal section of open channel.

Fig. 63 represents a longitudinal section of an open channel of any cross-section. In general the water surface will be approximately parallel to the bottom of the channel. The water surface at B is a distance H below the elevation of the water surface at A. Motion of the water is produced by gravity acting through the vertical distance H. If there were no resisting forces, the velocity of the water would be continually accelerated the same as with falling bodies. In this case the resisting force is the friction between the moving water and the wetted surface of the channel. H may be considered as a measure of this resistance.

Formulas for Flow of Water in Open Channels.—Referring to Fig. 63, the following nomenclature will be used:

a = Area of cross-section of channel in square feet.
p = Wetted perimeter or length of wetted border of cross-section of channel in feet.
$r = \frac{a}{p}$ = Mean hydraulic radius in feet.
l = Length of reach of channel considered in feet.
H = Difference in elevation of water surfaces in distance l.
$s = \frac{H}{l}$, commonly called the slope of water surface.
v = Mean velocity of water in feet per second.
$Q = av$ = Total discharge of channel in second-feet.
d = Diameter of circular conduits in feet.
n = Coefficients of roughness in Kutter's and Manning's formulas.
m = Coefficient of roughness in Bazin's formula.
f = Coefficient of roughness in Biel's formula.
t = Temperature coefficient in Biel's formula.
c = Coefficient in Chezy formula.
$K = \frac{1.486}{n}$ = Coefficient in Manning's formula.

The Chezy Formula.—The earliest formula for determining the flow of water in open channels (also used for pipes, see page 154) was suggested by Chezy in 1775. The Chezy formula for open channels is usually written

$$v = c\sqrt{rs} \tag{1}$$

This formula is based upon the assumption that the resistance to flow, H, varies directly as the square of the velocity, v, and area of wetted surface, pl, and inversely as the cross-sectional area of the channel, a.

From the limited data available at the time, Chezy believed c to be constant for all channels constructed of the same class of material and to vary only with the degree of roughness of the channel. Later investigators have concluded that c is a function of r, or r and s as well as a coefficient whose value depends upon the degree of roughness of the channel, and have developed formulas in accordance with this idea.

In the following pages are given a number of open channel formulas. The list includes the older formulas that have received common acceptance, and some of the more recent formulas, which have been based upon later compilations of experimental data.

The Kutter Formula.—The following formula for determining c in the Chezy formula ($v = c\sqrt{rs}$), published[1] by Ganguillet and Kutter in 1869, is commonly called the Kutter formula:

$$c = \frac{41.65 + \frac{0.00281}{s} + \frac{1.811}{n}}{1 + \frac{n}{\sqrt{r}}\left(41.65 + \frac{0.00281}{s}\right)} \tag{2}$$

Manning's formula, published[2] in 1890, gives the following value of c in the Chezy formula:

$$c = \frac{1.486}{n} r^{1/6} \tag{3}$$

The complete Manning's formula being

$$v = \frac{1.486}{n} r^{2/3} s^{1/2} = K r^{2/3} s^{1/2} \tag{4}$$

The expression $\frac{1.486}{n}$ in Manning's formula was designed to make the values of n correspond to the values of Kutter's n.

Values of n, in Kutter's formula, for different types of channels as given by the authors of the formula are as follows:

$n = 0.009$ for well-planed timber.
$n = 0.010$ for neat cement.
$n = 0.011$ for cement mortar with one-third sand.
$n = 0.012$ for unplaned timber.
$n = 0.013$ for ashlar and well-laid brickwork.
$n = 0.015$ for rough brickwork.
$n = 0.017$ for rubble masonry.
$n = 0.020$ for canals in firm gravel.
$n = 0.025$ for canals and rivers in good condition.
$n = 0.030$ for canals and rivers with stones and weeds.
$n = 0.035$ for canals and rivers in bad order.

The above values do not cover the range of present practice, and in many cases they are not in accordance with the results of later experiments. A more complete list of values of n has

[1] GANGUILLET and KUTTER: Flow of Water in Rivers and Other Channels. Translation by HERRING and TRAUTWINE, John Wiley and Sons, Publishers.

[2] ROBERT MANNING: Flow of Water in Open Channels and Pipes. *Trans. Inst. Civ. Eng. of Ireland*, 1890, vol. 20.

TABLE 73.—HORTON'S VALUES OF *n*. TO BE USED WITH KUTTER'S AND MANNING'S FORMULAS.

Surface	Best	Good	Fair	Bad
Uncoated cast-iron pipe	0.012	0.013	0.014	0.015
Coated cast-iron pipe	0.011	0.012*	0.013*	
Commercial wrought-iron pipe, black	0.012	0.013	0.014	0.015
Commercial wrought-iron pipe, galvanized	0.013	0.014	0.015	0.017
Smooth brass and glass pipe	0.009	0.010	0.011	0.013
Smooth lockbar and welded "OD" pipe	0.010	0.011*	0.013*	
Riveted and spiral steel pipe	0.013	0.015*	0.017*	
Vitrified sewer pipe	0.010 0.011	0.013*	0.015	0.017
Common clay drainage tile	0.011	0.012*	0.014*	0.017
Glazed brickwork	0.011	0.012	0.013*	0.015
Brick in cement mortar; brick sewers	0.012	0.013	0.015*	0.017
Neat cement surfaces	0.010	0.011	0.012	0.013
Cement mortar surfaces	0.011	0.012	0.013*	0.015
Concrete pipe	0.012	0.013	0.015*	0.016
Wood stave pipe	0.010	0.011	0.012	0.013
Plank Flumes:				
Planed	0.010	0.012*	0.013	0.014
Unplaned	0.011	0.013*	0.014	0.015
With battens	0.012	0.015*	0.016	
Concrete-lined channels	0.012	0.014*	0.016*	0.018
Cement-rubble surface	0.017	0.020	0.025	0.030
Dry-rubble surface	0.025	0.030	0.033	0.035
Dressed-ashlar surface	0.013	0.014	0.015	0.017
Semicircular metal flumes, smooth	0.011	0.012	0.013	0.015
Semicircular metal flumes, corrugated	0.0225	0.025	0.0275	0.030
Canals and Ditches:				
Earth, straight and uniform	0.017	0.020	0.0225*	0.025
Rock cuts, smooth and uniform	0.025	0.030	0.033*	0.035
Rock cuts, jagged and irregular	0.035	0.040	0.045	
Winding sluggish canals	0.0225	0.025*	0.0275	0.030
Dredged earth channels	0.025	0.0275*	0.030	0.033
Canals with rough stony beds, weeds on earth banks	0.025	0.030	0.035*	0.040
Earth bottom, rubble sides	0.028	0.030*	0.033*	0.035
Natural Stream Channels:				
(1) Clean, straight bank, full stage, no rifts or deep pools	0.025	0.0275	0.030	0.033
(2) Same as (1), but some weeds and stones	0.030	0.033	0.035	0.040
(3) Winding, some pools and shoals, clean	0.033	0.035	0.040	0.045
(4) Same as (3), lower stages, more ineffective slope and sections	0.040	0.045	0.050	0.055
(5) Same as (3), some weeds and stones	0.035	0.040	0.045	0.050
(6) Same as (4), stony sections	0.045	0.050	0.055	0.060
(7) Sluggish river reaches, rather weedy or with very deep pools	0.050	0.060	0.070	0.080
(8) Very weedy reaches	0.075	0.100	0.125	0.150

* Values commonly used in designing.

been prepared by Horton[1] from an examination of the best available experiments. These values were designed only for use in Kutter's formula but they will apply equally to Manning's formula (see discussion, pages 196 to 200). Horton's list of coefficients has the advantage of giving values which correspond to practically the entire range of experiments for each class of channel. The author does not recommend either Kutter's or Manning's formula for pipes but they are sometimes used for this purpose, especially for large pipes, and values of n for different classes of pipes may be valuable for reference. Horton's complete list is therefore given. The coefficients for common clay drainage tile have been added by the author. Horton's values of n with this addition are given in Table 73.

The Bazin Formula.—The following formula was proposed by Bazin in 1897. Like the Kutter formula it determines a value of c in the Chezy formula ($v = c\sqrt{rs}$).

$$c = \frac{157.6}{1 + \dfrac{m}{\sqrt{r}}} \tag{5}$$

The following values of m are given by Bazin:

$m = 0.109$ for smooth cement or planed wood.
$m = 0.290$ for planks, ashlar, and brick.
$m = 0.833$ for rubble masonry.
$m = 1.540$ for earth channels of very regular surface.
$m = 2.360$ for ordinary earth channels.
$m = 3.170$ for exceptionally rough channels encumbered with weeds and boulders.

The above list does not include all of the different types of channels that are being constructed at the present time. The values of m given are, moreover, averages and offer no clue to the range in variation to be expected for a given class of channels. Table 74 shows the range in values of m as determined from measurements of a large number of channels. It corresponds approximately to Horton's table of values of n. The range of results agrees quite closely with the values of m as determined from the 269 experiments tabulated by Scobey (see Appendix B).

[1] Robert E. Horton: Some Better Kutter's Formula Coefficients. *Engineering News*, Feb. 24 and May 4, 1916.

TABLE 74.—VALUES OF m FOR BAZIN'S FORMULA

	Best	Good	Fair	Bad
Vitrified sewer pipe	.10	.40	.60	.90
Common clay drain tile	.20	.30	.50	.90
Glazed brickwork	.10	.25	.40	.60
Brick in cement mortar	.25	.40	.60	.90
Neat cement surfaces	.00	.10	.25	.40
Cement-mortar surfaces	.10	.20	.40	.60
Concrete pipe	.25	.40	.60	.75
Plank flumes, planed	.00	.25	.40	.50
Plank flumes, unplaned	.10	.40	.50	.60
Plank flumes, with battins	.25	.60	.75	1.00
Concrete-lined channels	.25	.50	.75	1.00
Rubble masonry	.90	1.25	1.90	2.50
Dry rubble	1.90	2.50	2.90	3.15
Ashlar masonry	.40	.50	.65	.90
Smooth metal flumes	.10	.25	.40	.60
Corrugated metal flumes	1.60	1.90	2.20	2.50
Earth canals in good condition	.90	1.25	1.60	1.90
Earth canals with weeds, rocks, etc	1.90	2.50	3.15	3.80
Canals excavated in rock	2.50	3.15	3.70	4.20
Natural streams in good condition	1.90	2.50	3.15	3.80
Natural streams with weeds, rocks, etc	3.15	4.40	6.30	8.80

Biel's formula, proposed[1] in 1907 for flow in pipes and open channels, expressed in English units, may be written

$$v^2 = \frac{1811rs}{0.0663 + \frac{f}{\sqrt{r}} + \frac{8.2t}{(100f + 2)v\sqrt{r}}} \qquad (6)$$

in which f and t are respectively coefficients of roughness of the channel and viscosity of the water. It is claimed by the author of the formula that it applies to the flow of other liquids and to the flow of gases in pipes.

The values of the coefficient of roughness are:

f = 0.018 for smooth boards and wrought-iron pipes.
f = 0.036 for new cast-iron and smooth cement pipes.
f = 0.054 for rough boards and smooth brickwork.
f = 0.072 for smooth masonry or brick channels.
f = 0.290 for rough masonry.
f = 0.500 for canals in earth and regular streams.

[1] *Zeitschrift Verein deutsches Ingenieure,* Mittheilungen über Forscharbeiten, Heft 44.

f = 0.750 for canals and rivers with stones and weeds.
f = 1.060 for canals and rivers in bad condition.

The coefficient t varies with the temperature of the water as follows:

32°F., $t = 0.0179$
40°F., $t = 0.0157$
50°F., $t = 0.0135$
60°F., $t = 0.0115$
70°F., $t = 0.0097$

A large number of so-called exponential or logarithmic formulas for flow in open channels have been advocated during the past few years. Of these the following are given:

The Williams and Hazen Formula.

$$v = c_1 r^{0.67} s^{0.54} \tag{7}$$

c_1 = 205 to 185 for very smooth channels.
c_1 = 165 to 155 for ordinary unplaned plank.
c_1 = 155 to 125 for ordinary sewer crock.
c_1 = 155 to 120 for ordinary brick sewers.
c_1 = 105 to 75 for ordinary earth channels.
c_1 = 75 to 45 for rough natural channels.

Lea's[1] **formulas** for open channels give a varying coefficient and varying exponents for the different classes of channels, as follows:

For smooth channels lined with cement or planed boards

$$s = (0.000065 \text{ to } 0.00011)\frac{v^{1.75}}{r^{1.25}} \tag{8a}$$

For smooth channels lined with well-pointed brick, or concrete

$$s = (0.000065 \text{ to } 0.00011)\frac{v^{1.88}}{r^{1.15}} \tag{8b}$$

For channels lined with ashlar masonry or small pebbles

$$s = 0.00015\frac{v^{1.96}}{r^{1.4}} \tag{8c}$$

For channels lined with rubble masonry, large pebbles, rock, and exceptionally smooth earth channels free from deposits

$$s = 0.00023\frac{v^{1.96}}{r^{1.3 \text{ to } 1.5}} \tag{8d}$$

[1] F. C. Lea: Hydraulics, pp. 200–201.

For earth channels in ordinary condition

$$s = (0.00033 \text{ to } 0.00050) \frac{v^{2.1}}{r^{1.3 \text{ to } 1.5}} \tag{8e}$$

For earth channels of exceptional resistance

$$s = (0.00050 \text{ to } 0.00085) \frac{v^{2.1}}{r^{1.3 \text{ to } 1.5}} \tag{8f}$$

Barnes' formulas for open channels, published[1] in 1916, were adopted after a comprehensive investigation of available experimental data. The formulas for newly constructed channels are given. To allow for deterioration, in designing a conduit for a required capacity, a given percentage should be added to Q and the slope and channel conditions should be determined for this excess capacity. The following are Barnes' formulas for open channels.

For clean planed wood troughs or flumes. Add 8 per cent. to Q for purposes of design to allow for deterioration.

$$v = 223.3r^{0.660}s^{0.586} \text{ or } s = 0.0000981 \frac{v^{1.707}}{r^{1.126}} \tag{9a}$$

For clean unplaned wood troughs or flumes. Add 8 per cent. to Q to allow for deterioration.

$$v = 182.5r^{0.666}s^{0.569} \text{ or } s = 0.0001066 \frac{v^{1.757}}{r^{1.171}} \tag{9b}$$

For clean neat cement channels. Add 6 per cent. to Q to allow for deterioration.

$$v = 136.3r^{0.635}s^{0.484} \text{ or } s = 0.0000389 \frac{v^{2.066}}{r^{1.312}} \tag{9c}$$

For clean hard brick well-pointed conduits. Add 5 per cent. to Q to allow for deterioration.

$$v = 92.1r^{0.602}s^{0.466} \text{ or } s = 0.0000609 \frac{v^{2.146}}{r^{1.292}} \tag{9d}$$

For clean smooth-faced concrete conduits. Add 5 per cent. to Q to allow for deterioration.

$$v = 95.1r^{0.567}s^{0.471} \text{ or } s = 0.0000631 \frac{v^{2.123}}{r^{1.204}} \tag{9e}$$

For dressed masonry channels in cement with no projecting surfaces. Add 8 per cent. to Q to allow for deterioration.

$$v = 109.7r^{0.713}s^{0.483} \text{ or } s = 0.0000597 \frac{v^{2.070}}{r^{1.476}} \tag{9f}$$

[1] A. A. BARNES: Hydraulic Flow Reviewed, Spon and Chamberlain, Publishers.

For rock-faced masonry channels in cement. Add 8 per cent. to Q to allow for deterioration.

$$v = 80.5r^{0.658}s^{0.482} \text{ or } s = 0.0001112 \frac{v^{2.075}}{r^{1.355}} \qquad (9g)$$

For hammer dressed dry masonry water courses. Add 10 per cent. to Q to allow for deterioration.

$$v = 70.0r^{0.820}s^{0.500} \text{ or } s = 0.0002041 \frac{v^{2.000}}{r^{1.640}} \qquad (9h)$$

For earth canals in average working condition and rivers free from vegetation. No addition to Q.

$$v = 58.4r^{0.694}s^{0.496} \text{ or } s = 0.0002746 \frac{v^{2.016}}{r^{1.399}} \qquad (9i)$$

Discussion of Open-Channel Formulas

In the light of our present knowledge it would be difficult to say that any one of the foregoing formulas or sets of formulas possesses marked advantages from the standpoint of accuracy. Probably any of the formulas in experienced hands will give reasonably satisfactory results and yet no one of them will prove to be infallible under all conditions. In applying these formulas to practical problems the inexperienced man may find his results even more disappointing.

In any of the formulas listed, excepting the Barnes formulas, it is necessary to select a coefficient, representing the degree of roughness of the channel. Values of this coefficient corresponding to the range of fluctuation of experimental results accompany each of the formulas. From these values the coefficient best suited to the particular conditions must be selected. If the Barnes formulas are used the problem becomes one of selecting the formula corresponding to the proper type of channel. Since these formulas represent average conditions they do not indicate the limits of variation in results that may be expected from their use. In the author's opinion this feature is objectionable as pointed out in connection with pipe formulas (see discussion, pages 160 to 162).

As already stated it does not appear that any one formula has the advantage from considerations of relative accuracy. The adoption of a particular formula therefore becomes a matter of convenience or expediency. Unless some advantage is to be gained there appears to be no reason for discontinuing the use of an old and tried formula for the adoption of a more recent one.

The exponential formulas have the advantage of requiring a smaller table of coefficients than the older formulas but this fact does not simplify their solution. Odd exponents without corresponding tables of powers of numbers are awkward to handle.

It is important that the engineer who deals frequently with hydraulic problems should familiarize himsef with some particular formula and that he should think in terms of that formula in order that a certain value of coefficient will have a definite meaning to him. In this connection it must be admitted that the engineer will find it more convenient to have for his special formula the formula which has common acceptance in his locality. To the average American engineer "Kutter's *n*" has a very specific meaning.

The three formulas which have received general acceptance are the Kutter formula, the Bazin formula, and the Manning formula. Of the three formulas the Kutter formula has been used most extensively, and almost exclusively in the United States. In France the Bazin formula has to a large extent replaced the Kutter formula. In Australia and India the Manning formula has been extensively used. The further discussion of this subject will be limited to these three formulas.

Comparisons of Kutter, Manning, and Bazin Formulas

The following discussion will be based upon the hypothesis that each of the three formulas (formulas (2), (4), and (5), pages 190 and 192) will give equally good results in the hands of experienced men and that no one of them has any advantage from the standpoint of accuracy. It then becomes a question of deciding on the most suitable formula from considerations of simplicity and the advantages to be gained from using the formula that has been generally accepted.

The Bazin and Kutter formulas are each expressions for determining c in the Chezy formula ($v = c\sqrt{rs}$), page 189. In the Bazin formula c, not being a function of s, has one less variable than in the Kutter formula, in which it is a function of both r and s, and a table of values of c derived from the Bazin formula (Table 77, page 210) is more condensed and convenient for use than the corresponding table (Table 76, page 207) for Kutter's formula. In this regard the Bazin

formula has an advantage from the standpoint of simplicity. The objection to adopting the Bazin formula by engineers accustomed to the Kutter formula is that it will entail the necessity of becoming familiar with a new set of coefficients.

The coefficient K of the Manning formula varies only with n and thus possesses an advantage over either of the other formulas. The evident objection that the exponent of 2/3 for r adds a complication may be overcome by the use of tables. It will be shown later (pages 200 to 203) that, with the assistance of Tables 79 to 85 inclusive, the solution of problems by the Manning formula may be made simpler than is possible with either the Kutter or Bazin formulas.

The Kutter formula has been used almost exclusively in the United States and American engineers have been accustomed to think of open channels in terms of "Kutter's n." They have for this reason been reluctant to adopt a new formula involving the necessity of familiarizing themselves with a new set of coefficients. It remains to be shown, therefore, that the same n used in Kutter's and Manning's formulas gives practically identical results within the limits of our experimental knowledge and throughout the range of ordinary application. This will be shown to be the case and the author believes that the general adoption of the Manning formula, as a substitute for the Kutter formula, will be a step in advance.

Table 75, page 204, has been prepared to show the values of the coefficient of roughness in the three formulas which will give equivalent results. Values of c, in the Chezy formula ($v = c\sqrt{rs}$), between the extreme limits that will be encountered in practice, are selected for different hydraulic radii, and corresponding values of Kutter's n for various slopes, and Manning's n and Bazin's m are given.

This table is particularly instructive in showing the effect of slope on the value of c when determined from Kutter's formula and the conditions under which Manning's and Kutter's formulas give approximately the same results.

From an examination of Table 75 it will be seen that for channels having a hydraulic radius less than unity, Kutter's n when used in Manning's formula gives higher velocities than Kutter's formula, except for the smoother channels. For hydraulic radii from 1 to 10 feet the agreement between Kutter's and Manning's formulas is very close for all kinds of channels except for the flattest slopes. For hydraulic radii above 10

feet Manning's formula will in general give higher velocities than Kutter's formula, with the same value of n.

It will be observed that the close agreement between Manning's and Kutter's formulas occurs under the conditions which usually obtain in practice. Ordinary channels, excepting sewers and drain pipes, have hydraulic radii between 1 and 10 feet and slopes are not frequently less than 0.0001. Common values of Kutter's n used for designing vitrified pipe or concrete sewers or drains are from 0.013 to 0.015 and for these values Manning's and Kutter's formulas agree very closely, even for the smaller hydraulic radii. It should also be remembered that Kutter's formula is purely empirical and that the experiments on which it is based lie primarily within the range of hydraulic radii and channel conditions in which the agreement with Manning's formula is closest. There is, moreover, a question as to whether the slope has the effect on the value of c that Kutter assigned to it. The term $\frac{0.00281}{s}$ in the Kutter formula was introduced primarily to make the formula fit the experiments of Humphreys and Abbott[1] on the flow in the Mississippi River. The velocity measurements for these experiments were made by the double-float method and it is now believed that these measurements gave too high velocities. There is no doubt but that great uncertainty exists regarding the accuracy of the slope measurements which were made by means of an engineer's level. The smallest slope measured was 0.0000034, less than 0.02 foot per mile, and the difficulties of determining the elevations of water surface and the probable error of level work under such conditions, throws considerable doubt upon the accuracy of the work as a whole. Bazin, as a result of his investigation, decided that the slope did not effect the value of c in the Chezy formula and designed his formula accordingly.

Channels are usually constructed on slopes greater than 0.0001 and so in reality the correction for slope in Kutter's formula is not important, and especially so, in view of the uncertainty which exists in the proper selection of n. It is probably due to this fact that Kutter's formula has given such generally satisfactory results. In other words, the Kutter formula would doubtless give equal satisfaction if the terms

[1] Report on the Hydraulics of the Mississippi River, 1861.

involving s were omitted altogether, and the formula could be simplified without detracting from its accuracy. It certainly has not been demonstrated that the slope in any way effects the value of c in the Chezy formula and it appears more consistent, to use a formula of the simpler form in which terms of no particular significance, that are based upon the results of uncertain experimental data, do not exist.

In order to determine the comparative values of the coefficients in Kutter's, Manning's and Bazin's formulas under actual working conditions, the author has had the computations in the experiments listed by Scobey[1] for 269 channels, extended to include Manning's n and Bazin's m. The results of this work are given in Table 112, Appendix *B*. It will be seen that the agreement between Manning's n and Kutter's n is most remarkable, and the author submits this table as the best evidence that the two formulas give results agreeing well within the limits of uncertainty which must exist in selecting the proper value of n, for all working conditions.

It will be noted that Bazin's formula cannot give a value of c greater than 157.6 unless m becomes negative. Scobey's experiments show a negative m in a few instances.

Solution of Kutter and Bazin Formulas.—The solution of each formula will be simplified by the use of tables. Table 76, page 207, gives values of c by the Kutter formula corresponding to different values of s, r and n. Table 77, page 210, gives values of c by the Bazin formula corresponding to different values of r and m. With the value of c determined by either of these tables the Chezy formula

$$v = c\sqrt{rs} \qquad (1)$$

may be readily solved. Table 83, page 224, containing the square roots of decimal numbers will assist in the operation. r for trapezoidal sections and circular segments may be obtained from Tables 79 and 80 respectively, pages 211 and 212. There are three general types of problems, the methods of solving which are given below. n is given in each case.

1. The cross-sectional dimensions and slope of channel are given; to obtain v or Q.

Solution.—Compute r from the relation $r = a/p$ or obtain

[1] Fred C. Scobey: The Flow of Water in Irrigation Channels. Bulletin No. 194, U. S. Department of Agriculture.

it from Table 79 or 80. Take c from Table 75 or 76. Solve for v and if Q is desired $Q = av$.

2. The velocity and dimensions of cross-section of channel are given; to obtain s.

Solution.—Compute r or take it from Table 79 or 80. Take c from Table 75 or 76 (If Kutter's formula is used approximate value of s must be assumed). If preferred the Chezy formula may be written

$$s = \frac{v^2}{c^2 r} \tag{1a}$$

from which s may be obtained. If Kutter's formula is used, a second solution may be required if the assumed s does not agree approximately with the computed s.

3. The discharge and slope are given; to obtain dimensions of cross-section of channel.

Solution.—The proportional dimensions must be given; as for example the channel is to be of semicircular section flowing three-fourths full, or trapezoidal section with side slopes of 2 to 1 and bottom width three times the depth of water.

Considering the latter case, let D represent the depth of water. Then from Table 80 it is seen that $r = 0.670D$. From Table 76 select a value of c corresponding to an assumed value of r. Also for this example $v = Q/a = \frac{Q}{5D^2}$. By substituting the Chezy formula may now be written in terms of known quantities and D and the resulting equation may be solved for D.

A similar process may be followed for channels of segmental circular section, using Table 79 in place of Table 80.

Solution of Manning Formula.—The solution of this formula will be simplified by the use of tables. The application of Tables 81, 82 and 85, pages 215, 222 and 227, is explained below. Tables 83 and 84, pages 224 and 225, will assist in evaluating $s^{1/2}$ and $r^{2/3}$. The coefficient n may be applied directly or Table 78, page 210, may be used if desired. For convenience of reference the Manning formula is here repeated.

$$v = \frac{1.486}{n} r^{2/3} s^{1/2} \tag{4}$$

The method of solving the three general types of open-channel problems is indicated below. n is given in each case.

1. The cross-sectional dimensions and slope of channel are given; to obtain v or Q.

Solution.—Compute r or obtain it from Tables 79 or 80, pages 211 and 212. From Table 81, page 215, find the value of nv corresponding to this r and the given s. Divide the tabulated value of nv by n to obtain v. If Q is desired $Q = av$.

2. The velocity and dimensions of cross-section of channel are given; to obtain s.

Solution.—For solving problems of this type the Manning formula may be conveniently expressed in the form

$$s = \frac{(nv)^2}{2.2082r^{4/3}} \tag{4a}$$

Values of $\dfrac{1}{2.2082r^{4/3}}$ are given in Table 82. To determine s multiply the tabulated value by $(nv)^2$. Approximate values of s may be obtained by interpolation from Table 81.

3. The discharge and slope are given; to obtain dimensions of cross-section of channel. Two general cases will be described.

Solution for Canals of Trapezoidal Section.—Referring to the section shown in Fig. 64. Let b be the bottom width of canal and D the depth of water. Also let $e/D = z$ and $b/D = y$. These two ratios must be given to complete the problem. Also $r = c_xD$, in which c_x is the factor, taken from Table 80. The equation for D may now be expressed

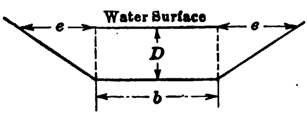


Fig. 64.—Canal section.

$$D = \left(\frac{0.673Qn}{c_x^{2/3}s^{1/2}(y + z)}\right)^{3/8} \tag{4b}$$

Table 85, page 227, gives $3/8$ powers of numbers. After D has been determined, b may be obtained from the relation

$$b = yD$$

For example, it is required to find the bottom width of a canal, where $Q = 300$ second-feet, $s = 0.0002$, the side slopes of the canal are to be 2 to 1 and the depth of water in the canal is to be one-third of the bottom width. n is taken as 0.0225.

From the above data $y = 3$ and $z = 2$. From Table 80

$c_x = 0.670$ and from Table 84 $c_x^{3/8} = 0.765$. From Table 83, $s^{1/2} = 0.01414$ whence

$$D = \left(\frac{0.673 \times 300 \times 0.0225}{0.765 \times 0.01414(3 + 2)}\right)^{3/8} = 84.0^{3/8}$$

and from Table 85, $D = 5.27$. $b = 3D = 15.81$.

Solution for Conduits of Circular Section.—Let A, P and R be respectively the area, hydraulic radius, and wetted perimeter for any circular conduit of diameter d flowing full and a, p, and r the corresponding elements when flowing with a depth D, Fig. 65. Let $a = c_aA$, $p = c_pP$, $r = c_rR = c_rd/4 = c_dd$. These coefficients are all functions of D/d.

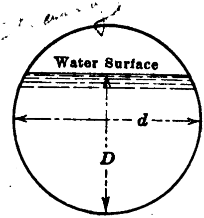


FIG. 65.—Circular conduit.

The formula for d may be written

$$d = \left(\frac{2.159Qn}{c_ac_r^{2/3}s^{1/2}}\right)^{3/8} = \left(\frac{KQn}{s^{1/2}}\right)^{3/8} \qquad (4c)$$

Table 79, page 211, contains values of K and also values of c_a, c_p, c_r, and c_d. Table 85, page 227, gives $3/8$ powers of numbers.

For example, a circular conduit is to flow $3/4$ full when carrying 20 second-feet of water. $s = 0.0015$ and $n = 0.015$, d is required.

From Tables 79 and 83 $K = 2.37$ and $S^{1/2} = 0.03873$, whence

$$d = \left(\frac{2.37 \times 20 \times 0.015}{0.03873}\right)^{3/8} = 18.36^{3/8}$$

and from Table 85 $d = 2.98$ feet.

Manning's formula gives Q a maximum when $D = 0.938d$ and $K = 2.007$. The minimum diameter of a circular conduit for a given discharge is therefore,

$$d = \left(\frac{2Qn}{s^{1/2}}\right)^{3/8} \qquad (4d)$$

Formula (4*d*) should be used when the flow is unobstructed and the diameter for a given maximum discharge is required. If water is backed up so that the conduit flows full, formula (4*c*) with $K = 2.159$ will probably apply more accurately.

Diagrams for Solution of Manning Formula.—The Manning formula is readily adaptable to graphical solution. Diagram 1, page 230, is intended for sewers and small canals and Diagram 2, opposite page 230, gives a general solution of the formula for channels having hydraulic radii from 0 to 30 feet.

TABLE 75.—COMPARISON OF COEFFICIENTS OF ROUGHNESS IN KUTTER'S, MANNING'S AND BAZIN'S FORMULAS

Hydraulic radius r, feet	c, Chezy formula	n, Kutter's formula							n, Manning's formula	m, Bazin's formula
		$s =$ .000025	$s =$ .00005	$s =$ .0001	$s =$ .0002	$s =$ .0004	$s =$ .001	$s =$ .01		
0.1	10	.040	.042	.044	.045	.047	.049	.050	.101	4.67
	15	.028	.032	.034	.035	.037	.038	.039	.067	3.01
	20	.022	.025	.027	.028	.029	.031	.032	.051	2.18
	30	.016	.018	.020	.022	.022	.023	.023	.034	1.34
	40	.013	.015	.016	.017	.018	.019	.019	.025	.930
	50	.011	.012	.014	.015	.015	.016	.016	.020	.681
	75	....	.009	.010	.011	.011	.012	.012	.014	.348
	100	....	....	.....	.009	.009	.010	.010	.010	.182
0.2	15	.037	.040	.041	.042	.042	.043	.044	.076	4.25
	20	.029	.032	.034	.036	.037	.038	.039	.057	3.08
	30	.021	.023	.024	.026	.027	.028	.028	.038	1.90
	40	.017	.018	.020	.021	.022	.022	.023	.028	1.31
	50	.014	.015	.017	.018	.018	.019	.019	.023	.963
	75	.010	.011	.012	.013	.013	.014	.014	.015	.492
	100	....	.009	.010	.010	.011	.011	.011	.011	.258
	125	....	....	.....	.009	.009	.009	.009	.009	.117
0.4	20	.038	.040	.042	.045	.045	.046	.046	.064	4.35
	30	.027	.029	.030	.032	.032	.033	.034	.043	2.69
	40	.021	.022	.024	.025	.026	.026	.027	.032	1.86
	50	.017	.019	.020	.021	.022	.022	.023	.026	1.36
	75	.012	.013	.015	.015	.016	.016	.016	.017	.696
	100	.010	.011	.0115	.012	.012	.013	.013	.013	.364
	125	....	.009	.010	.010	.010	.010	.011	.010	.165
	150	....	....	.....	.009	.009	.009	.009	.009	.032
0.6	30	.031	.033	.035	.036	.036	.037	.038	.046	3.29
	40	.024	.026	.027	.028	.029	.030	.030	.034	2.28
	50	.020	.021	.023	.024	.024	.024	.025	.027	1.67
	75	.014	.015	.016	.017	.017	.017	.017	.018	.853
	100	.011	.012	.013	.013	.013	.013	.014	.014	.446
	125	.009	.010	.010	.011	.011	.011	.011	.011	.202
	150	....	....	.009	.009	.009	.009	.009	.009	.039
0.8	30	.035	.036	.038	.039	.040	.040	.041	.048	3.80
	40	.027	.028	.030	.031	.031	.031	.032	.036	2.63
	50	.022	.023	.024	.025	.026	.026	.026	.029	1.93
	75	.015	.017	.017	.017	.018	.018	.018	.019	.985
	100	.012	.013	.013	.013	.014	.014	.014	.014	.515
	125	.010	.010	.011	.011	.012	.012	.012	.0115	.233
	150	....	.009	.009	.010	.010	.010	.010	.010	.045

TABLE 75 (*Continued*)

COMPARISON OF COEFFICIENTS OF ROUGHNESS IN KUTTER'S, MANNING'S AND BAZIN'S FORMULAS

Hydraulic radius r, feet	c, Chezy formula	n, Kutter's formula							n, Manning's formula	m, Bazin's formula
		$s =$ .000025	$s =$ .00005	$s =$ .0001	$s =$ .0002	$s =$ .0004	$s =$ .001	$s =$ .01		
1.0	30	.037	.039	.041	.042	.042	.043	.043	.050	4.25
	40	.029	.030	.031	.033	.033	.034	.034	.037	2.94
	50	.024	.025	.026	.027	.027	.028	.028	.030	2.15
	75	.016	.017	.018	.019	.019	.019	.019	.020	1.10
	100	.013	.014	.014	.014	.015	.015	.015	.015	.576
	125	.010	.011	.012	.012	.012	.012	.012	.012	.261
	150	.009	.009	.010	.010	.010	.010	.010	.010	.050
1.5	30	.043	.044	.045	.046	.047	.047	.048	.053	5.20
	40	.034	.035	.036	.037	.037	.037	.037	.040	3.60
	50	.027	.029	.029	.030	.030	.030	.031	.032	2.63
	75	.019	.020	.020	.020	.021	.021	.022	.021	1.35
	100	.014	.015	.015	.016	.016	.016	.016	.016	.705
	125	.012	.012	.012	.013	.013	.013	.013	.013	.319
	150	.010	.010	.011	.011	.011	.011	.011	.011	.061
2.0	40	.037	.038	.039	.040	.040	.040	.040	.042	4.16
	50	.030	.031	.032	.032	.032	.033	.033	.033	3.04
	75	.021	.022	.022	.022	.022	.022	.022	.022	1.56
	100	.016	.016	.016	.017	.017	.017	.017	.017	.814
	125	.013	.013	.013	.013	.013	.013	.013	.013	.369
	150	.011	.011	.011	.011	.011	.011	.011	.011	.071
	175	.009	.009	.010	.010	.010	.010	.010	.010	−.114
3.0	40	.043	.043	.044	.044	.044	.044	.044	.045	5.09
	50	.035	.035	.036	.036	.036	.036	.036	.036	3.73
	75	.024	.024	.024	.024	.024	.024	.024	.024	1.91
	100	.018	.018	.018	.018	.018	.018	.018	.018	.998
	125	.014	.014	.014	.014	.014	.014	.014	.014	.452
	150	.012	.012	.012	.012	.012	.012	.012	.012	.087
	175	.010	.010	.010	.010	.010	.010	.010	.010	−.173
4.0	50	.039	.039	.039	.039	.039	.039	.039	.037	4.30
	75	.026	.026	.025	.025	.025	.025	.025	.025	2.20
	100	.019	.019	.019	.019	.019	.019	.019	.019	1.15
	125	.015	.015	.015	.015	.015	.015	.015	.015	.522
	150	.013	.013	.012	.012	.012	.012	.012	.012	.100
	175	.011	.011	.011	.011	.011	.011	.011	.011	−.200
	200	.009	.009	.009	.009	.009	.009	.009	.009	−.424

TABLE 75 (*Concluded*)

COMPARISON OF COEFFICIENTS OF ROUGHNESS IN KUTTER'S, MANNING'S AND BAZIN'S FORMULAS

Hydraulic radius r, feet	c, Chezy formula	n, Kutter's Formula							n, Manning's formula	m, Bazin's formula
		$s =$ .000025	$s =$ .00005	$s =$ .0001	$s =$ .0002	$s =$ .0004	$s =$ .001	$s =$ .01		
6.0	50	.045	.045	.044	.043	.042	.041	.041	.040	5.27
	75	.030	.029	.029	.028	.027	.027	.027	.027	2.70
	100	.022	.021	.021	.020	.020	.020	.020	.020	1.41
	125	.017	.017	.016	.016	.016	.016	.016	.016	.639
	150	.014	.014	.013	.013	.013	.013	.013	.013	.122
	175	.012	.012	.011	.011	.011	.011	.011	.011	− .245
	200	.010	.010	.010	.010	.010	.010	.010	.010	− .519
8.0	50	.048	.048	.047	.046	.045	.044	.044	.042	6.09
	75	.033	.031	.030	.029	.028	.028	.028	.028	3.11
	100	.024	.023	.022	.021	.021	.020	.020	.021	1.63
	125	.019	.018	.017	.017	.016	.016	.016	.017	.738
	150	.015	.014	.014	.014	.013	.013	.013	.014	.141
	175	.013	.012	.012	.011	.011	.011	.011	.012	− .283
	200	.011	.010	.010	.010	.010	.010	.010	.010	− .600
10.0	75	.039	.034	.032	.031	.030	.030	.030	.029	3.48
	100	.027	.024	.023	.022	.022	.021	.021	.022	1.82
	125	.019	.018	.018	.017	.017	.017	.016	.017	.825
	150	.016	.015	.014	.014	.014	.014	.014	.015	.158
	175	.013	.013	.012	.012	.012	.012	.011	.012	− .316
	200	.011	.011	.010	.010	.010	.010	.010	.011	− .670
	225	.010	.010	.009	.009	.009	.009	.009	.010	− .949
20.0	75	.045	.041	.037	.036	.034	.033	.033	.033	4.92
	100	.033	.029	.026	.025	.024	.023	.023	.024	2.58
	125	.024	.021	.020	.019	.018	.018	.018	.020	1.17
	150	.019	.017	.016	.015	.015	.014	.014	.016	.224
	175	.016	.014	.013	.012	.012	.012	.012	.014	− .447
	200	.013	.012	.011	.011	.010	.010	.010	.012	− .948
	225	.011	.010	.010	.009	.009	.009	.009	.011	−1.34
30.0	75	.050	.047	.041	.039	.036	.035	.034	.035	6.08
	100	.037	.031	.028	.026	.025	.024	.024	.026	3.16
	125	.027	.023	.021	.019	.019	.018	.018	.021	1.43
	150	.022	.018	.016	.015	.015	.015	.015	.018	.274
	175	.017	.015	.013	.013	.012	.012	.012	.015	− .548
	200	.014	.012	.011	.011	.011	.010	.010	.013	−1.16
	225	.012	.011	.010	.010	.009	.009	.009	.012	−1.64

TABLE 76.—VALUES OF c FROM KUTTER'S FORMULA FOR USE IN THE CHEZY FORMULA $v = c\sqrt{rs}$

r \ n	.009	.010	.011	.012	.013	.014	.015	.017	.020	.0225	.025	.030	.035	.040
Slope s = .00005 = 1 in 20,000 = 0.264 feet per mile														
.1	78	67	59	52	47	43	39	33	26	22	20	16	13	11
.2	100	87	77	68	62	56	51	44	35	30	26	21	18	15
.3	114	99	88	79	71	65	59	50	41	36	31	25	21	18
.4	124	109	97	88	79	72	66	57	46	40	35	28	24	20
.6	139	122	109	98	90	82	76	65	53	46	41	33	28	24
.8	150	133	119	107	98	90	83	71	59	52	46	37	31	27
1.0	158	140	126	114	104	96	89	77	64	56	49	40	34	29
1.5	173	154	139	126	116	107	99	87	72	64	57	47	40	34
2.	184	164	148	135	124	115	10'	94	79	70	62	51	44	38
3.	198	178	161	148	136	127	118	104	88	79	71	59	50	44
*3.28	201	181	164	151	139	129	121	106	91	81	72	60	52	46
4.	207	187	170	156	145	135	126	111	95	85	77	64	56	49
6.	220	199	182	168	156	146	137	122	105	94	85	72	63	56
10.	234	212	195	181	169	158	149	134	116	105	96	82	72	64
20.	250	228	211	196	184	174	165	149	131	120	110	96	85	77
50.	266	245	228	213	201	190	181	165	148	136	127	112	101	93
100.	275	254	237	222	210	200	190	175	158	146	137	123	112	104
Slope s = .0001 = 1 in 10,000 = 0.528 feet per mile														
.1	90	78	68	60	54	49	44	37	30	25	22	17	14	12
.2	112	98	86	76	69	63	57	48	39	33	29	23	19	16
.3	125	109	97	87	78	72	65	56	45	39	34	27	22	19
.4	136	119	106	95	86	79	72	62	50	43	38	31	25	22
.6	149	131	118	105	96	88	81	70	57	50	44	35	30	25
.8	158	140	126	114	103	95	88	76	63	55	48	39	33	28
1.0	166	147	132	120	109	101	93	81	67	59	52	42	35	31
1.5	178	159	144	130	120	111	103	89	75	66	59	48	41	35
2.	187	168	151	138	127	118	109	96	81	71	64	53	45	39
3.	198	178	162	149	137	127	119	104	89	79	71	59	51	45
4.	206	186	169	155	143	134	125	111	94	84	76	64	55	49
6.	215	195	178	164	152	142	134	119	102	92	84	71	61	54
10.	226	205	188	174	162	152	143	128	111	100	92	78	69	62
20.	237	216	200	185	173	163	154	139	122	111	102	89	79	71
50.	249	227	211	197	185	175	166	151	134	123	114	100	91	83
100.	255	234	218	204	191	181	172	158	140	130	121	108	98	91

* Values of c are the same for all slopes when r = 3.28 feet.

Table 76 (*Continued*)

Values of c from Kutter's Formula for Use in the Chezy Formula $v = c\sqrt{rs}$

r \ n	.009	.010	.011	.012	.013	.014	.015	.017	.020	.0225	.025	.030	.035	.040
Slope s = .0002 = 1 in 5000 = 1.056 feet per mile														
.1	99	85	74	65	59	53	48	41	32	27	24	18	15	12
.2	121	105	93	83	74	67	61	52	42	36	31	25	21	17
.3	133	116	103	92	83	76	69	59	48	42	36	29	24	20
.4	143	125	112	100	91	83	76	65	53	46	40	32	27	23
.6	155	138	122	111	100	92	85	73	60	52	46	37	31	26
.8	164	145	131	118	107	99	91	79	65	57	50	41	34	29
1.0	170	151	136	123	113	104	96	83	69	60	54	44	37	32
1.5	181	162	146	133	122	113	105	91	77	67	60	49	42	36
2.	188	170	154	140	129	119	111	97	82	72	64	54	45	40
3.	200	179	163	149	137	128	119	105	89	79	72	59	51	45
4.	205	185	168	155	143	133	125	111	94	84	76	63	55	48
6.	213	193	176	162	150	140	132	117	100	90	82	69	60	53
10.	222	201	185	170	158	148	140	125	108	98	89	76	67	60
20.	231	210	194	180	168	158	149	134	117	106	98	85	76	68
50.	240	220	203	189	177	167	158	143	126	116	108	94	85	78
100.	245	224	208	194	182	172	163	148	131	121	113	99	90	83
Slope s = .0004 = 1 in 2500 = 2.112 feet per mile														
.1	104	89	78	69	62	56	50	43	34	29	25	19	16	13
.2	126	110	97	87	78	71	65	54	44	37	32	25	21	18
.3	138	120	107	96	87	79	73	62	50	43	37	30	24	21
.4	148	129	115	104	94	86	79	68	55	47	42	33	27	23
.6	157	140	126	113	103	95	87	75	62	54	47	38	31	27
.8	166	148	133	121	110	101	93	81	67	58	51	42	35	30
1.0	172	154	138	125	115	106	98	85	70	62	55	45	37	32
1.5	183	164	148	135	124	114	106	93	78	68	61	50	42	37
2.	190	170	154	141	130	120	112	98	83	73	65	54	45	40
3.	199	179	162	149	138	128	119	105	89	79	71	59	51	45
4.	204	184	168	154	142	133	124	110	94	84	76	63	55	48
6.	211	191	175	161	149	139	130	116	99	89	81	69	60	53
10.	219	199	183	168	157	146	138	123	107	96	88	75	66	59
20.	227	207	190	176	164	154	146	131	115	104	96	83	73	66
50.	235	215	198	184	173	162	154	139	123	112	104	91	82	75
100.	239	219	203	189	177	167	158	143	127	116	108	96	87	80

TABLE 76 (*Concluded*)

VALUES OF c FROM KUTTER'S FORMULA FOR USE IN THE CHEZY FORMULA $v = c\sqrt{rs}$

r \ n	.009	.010	.011	.012	.013	.014	.015	.017	.020	.0225	.025	.030	.035	.040
Slope s = .001 = 1 in 1000 = 5.28 feet per mile														
.1	110	94	83	73	65	59	54	45	36	30	27	21	17	14
.2	129	113	99	89	81	73	66	57	45	39	34	27	22	18
.3	141	124	109	98	89	81	74	63	51	44	39	30	25	21
.4	150	131	117	105	96	88	80	69	56	48	43	34	28	24
.6	161	142	127	115	104	96	88	76	63	55	48	39	32	27
.8	169	150	134	122	111	102	94	82	68	59	52	42	35	30
1.0	175	155	139	127	116	107	99	86	71	62	56	45	38	33
1.5	184	165	149	136	124	115	108	93	78	69	62	50	43	37
2.	191	171	155	142	130	121	112	98	83	73	66	54	46	40
3.	199	179	163	149	138	128	119	105	89	79	71	59	51	45
4.	204	184	168	154	142	133	124	110	93	83	75	63	54	48
6.	211	190	174	160	149	139	130	116	99	89	81	68	59	52
10.	218	197	181	167	155	145	136	122	105	95	87	74	65	58
20.	225	205	188	175	163	153	144	129	113	102	94	81	72	65
50.	232	212	196	182	170	160	151	137	120	110	101	89	79	72
100.	236	216	200	186	174	164	155	141	124	114	105	94	85	77
Slope s = .01 = 1 in 100 = 52.8 feet per mile														
.1	110	95	83	74	66	60	54	46	36	31	27	21	17	14
.2	130	114	100	90	81	74	67	57	46	39	34	27	22	19
.3	143	125	111	100	90	83	76	64	52	45	39	31	25	22
.4	151	133	119	107	98	89	82	70	57	49	44	35	29	24
.6	162	143	129	116	106	98	90	77	64	55	49	39	33	28
.8	170	151	135	123	112	103	95	82	68	60	53	43	35	31
1.0	175	156	141	128	117	108	99	87	72	63	56	45	38	33
1.5	185	165	149	136	125	116	107	94	79	69	62	51	43	37
2.	191	171	155	142	130	121	112	99	83	74	66	55	46	40
3.	199	179	162	149	138	128	119	105	89	79	71	59	51	45
4.	204	184	167	154	142	132	123	109	93	83	76	63	55	48
6.	210	190	173	160	148	138	129	115	99	88	81	68	59	52
10.	217	196	180	166	154	145	136	121	105	94	86	74	65	58
20.	225	204	187	173	161	152	143	128	112	101	93	80	71	64
50.	231	210	194	181	168	158	150	135	119	108	100	87	78	71
100.	235	214	197	184	172	162	153	139	122	112	104	91	82	75

NOTE.—For slopes greater than .01 c remains practically constant.

TABLE 77.—VALUES OF c FROM BAZIN'S FORMULA FOR USE IN THE CHEZY FORMULA $v = c\sqrt{rs}$

Hydraulic radius, r in feet	$m =$ .109	$m =$ .290	$m =$ .833	$m =$ 1.54	$m =$ 2.35	$m =$ 3.17
.1	117	82	43	27	19	14
.2	127	96	55	35	25	19
.3	131	103	63	41	30	23
.4	135	108	68	46	32	26
.5	137	112	72	50	37	29
.6	139	116	76	53	39	31
.8	141	119	82	58	43	35
1.0	142	122	86	62	47	38
1.25	144	125	90	66	51	41
1.5	145	128	94	70	54	44
1.75	146	130	97	73	57	46
2.0	147	132	99	76	59	49
2.5	148	134	103	80	64	53
3.	149	136	107	84	67	56
4.	150	138	111	89	72	61
5.	151	140	115	94	77	65
6.	151	142	118	98	80	69
8.	152	144	122	102	86	74
10.	153	145	125	106	90	79
12.	153	145	127	109	94	82
15.	153	146	130	113	98	87
20.	154	148	133	117	103	92
30.	154	150	137	123	110	100
40.	155	151	139	127	115	105
50.	155	152	141	129	119	108

TABLE 78.—VALUES OF K IN MANNING'S FORMULA CORRESPONDING TO DIFFERENT VALUES OF n. $K = \frac{1.486}{n}$

n	K	n	K	n	K	n	K	n	K
.009	165	.015	99	.021	71	.030	50	.050	30
.010	149	.016	93	.022	68	.0325	46	.060	25
.011	135	.017	87	.023	65	.035	43	.070	21
.012	124	.018	83	.024	62	.0375	40	.080	19
.013	114	.019	78	.025	59	.040	37	.090	17
.014	106	.020	74	.0275	54	.045	33	.100	15

Table 79.—Ratios for Determining Hydraulic Elements of Circular Conduits Flowing Part Full. See Page 203 for Nomenclature

$\frac{D}{d}$	$\frac{a}{A}$	$\frac{p}{P}$	$\frac{r}{R}$	$\frac{r}{d}$	$\frac{2.159}{C_a C_r^{2/3}}$	$\frac{D}{d}$	$\frac{a}{A}$	$\frac{p}{P}$	$\frac{r}{R}$	$\frac{r}{d}$	$\frac{2.159}{C_a C_r^{2/3}}$
.	C_a	C_p	C_r	C_d	K		C_a	C_p	C_r	C_d	K
.01	.0017	.0638	.027	.007	......	.51	.5127	.5064	1.012	.253	4.18
.02	.0048	.0904	.053	.013	3210.	.52	.5255	.5128	1.025	.256	4.04
.03	.0087	.1108	.080	.020	1340.	.53	.5382	.5191	1.037	.259	3.91
.04	.0134	.1282	.105	.026	725.	.54	.5509	.5255	1.048	.262	3.80
.05	.0187	.1436	.130	.033	450.	.55	.5635	.5319	1.060	.265	3.69
.06	.0245	.1575	.156	.039	305.	.56	.5762	.5383	1.070	.268	3.58
.07	.0308	.1705	.181	.045	220.	.57	.5888	.5447	1.081	.270	3.48
.08	.0375	.1826	.205	.051	166.	.58	.6014	.5511	1.091	.273	3.39
.09	.0445	.1940	.230	.057	129.	.59	.6140	.5576	1.101	.275	3.30
.10	.0520	.2048	.254	.063	103	.60	.6265	.5641	1.111	.278	3.21
.11	.0599	.2152	.278	.070	84.6	.61	.6389	.5706	1.120	.280	3.14
.12	.0680	.2252	.302	.075	70.6	.62	.6513	.5771	1.129	.282	3.06
.13	.0764	.2348	.325	.081	59.7	.63	.6636	.5837	1.137	.284	2.99
.14	.0851	.2442	.348	.087	51.2	.64	.6759	.5903	1.145	.286	2.92
.15	.0941	.2531	.372	.093	44.4	.65	.6881	.5969	1.153	.288	2.86
.16	.1033	.2619	.394	.099	38.8	.66	.7002	.6037	1.160	.290	2.79
.17	.1127	.2706	.417	.104	34.3	.67	.7122	.6105	1.167	.292	2.73
.18	.1224	.2790	.439	.110	30.5	.68	.7241	.6173	1.173	.293	2.68
.19	.1323	.2871	.461	.115	27.4	.69	.7360	.6241	1.179	.295	2.63
.20	.1424	.2952	.482	.121	24.7	.70	.7477	.6310	1.185	.296	2.58
.21	.1527	.3031	.504	.126	22.3	.71	.7593	.6380	1.190	.298	2.53
.22	.1631	.3108	.525	.131	20.3	.72	.7708	.6450	1.195	.299	2.49
.23	.1737	.3184	.546	.136	18.6	.73	.7822	.6521	1.199	.300	2.45
.24	.1845	.3259	.566	.142	17.1	.74	.7934	.6593	1.203	.301	2.41
.25	.1955	.3333	.587	.147	15.8	.75	.8045	.6667	1.207	.302	2.37
.26	.2066	.3407	.607	.152	14.6	.76	.8155	.6741	1.210	.302	2.33
.27	.2178	.3479	.626	.157	13.5	.77	.8263	.6816	1.212	.303	2.30
.28	.2292	.3550	.646	.161	12.6	.78	.8369	.6892	1.214	.304	2.27
.29	.2407	.3620	.665	.166	11.8	.79	.8473	.6969	1.216	.304	2.24
.30	.2523	.3690	.684	.171	11.0	.80	.8576	.7048	1.217	.304	2.21
.31	.2640	.3759	.702	.176	10.35	.81	.8677	.7129	1.217	.304	2.18
.32	.2759	.3827	.721	.180	9.74	.82	.8776	.7210	1.217	.304	2.16
.33	.2878	.3895	.739	.185	9.18	.83	.8873	.7294	1.216	.304	2.14
.34	.2998	.3963	.757	.189	8.67	.84	.8967	.7381	1.215	.304	2.11
.35	.3119	.4031	.774	.193	8.21	.85	.9059	.7469	1.213	.303	2.09
.36	.3241	.4097	.791	.198	7.78	.86	.9149	.7558	1.210	.303	2.08
.37	.3364	.4163	.808	.202	7.40	.87	.9236	.7652	1.207	.302	2.06
.38	.3487	.4229	.825	.206	7.04	.88	.9320	.7748	1.203	.301	2.05
.39	.3611	.4295	.841	.210	6.71	.89	.9401	.7848	1.198	.299	2.04
.40	.3735	.4359	.857	.214	6.41	.90	.9480	.7952	1.192	.298	2.03
.41	.3860	.4424	.873	.218	6.13	.91	.9555	.8060	1.185	.296	2.02
.42	.3986	.4489	.888	.222	5.86	.92	.9625	.8174	1.177	.294	2.01
.43	.4112	.4553	.903	.226	5.62	.93	.9692	.8295	1.168	.292	2.01
.44	.4238	.4617	.918	.229	5.39	.94	.9754	.8425	1.158	.289	2.01
.45	.4365	.4681	.932	.233	5.18	.95	.9813	.8564	1.146	.286	2.01
.46	.4491	.4745	.946	.236	4.99	.96	.9866	.8718	1.132	.283	2.02
.47	.4618	.4809	.960	.240	4.80	.97	.9913	.8892	1.115	.279	2.03
.48	.4745	.4872	.974	.243	4.63	.98	.9952	.9096	1.094	.274	2.04
.49	.4873	.4936	.987	.247	4.47	.99	.9983	.9362	1.066	.267	2.07
.50	.5000	.5000	1.000	.250	4.32	1.00	1.0000	1.0000	1.000	.250	2.16

TABLE 80.—FOR DETERMINING HYDRAULIC RADIUS, r, FOR TRAPEZOIDAL CHANNELS OF VARIOUS SIDE SLOPES

Let $x = \frac{\text{depth of water}}{\text{bottom width of channel}} = \frac{D}{b}$ and c_x = tabulated value. Then $r = c_xD$

x	Side slopes of channel, ratio of horizontal to vertical									
	Vertical	¼–1	½–1	¾–1	1–1	1½–1	2–1	2½–1	3–1	4–1
.00	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
.01	.980	.982	.983	.983	.982	.980	.976	.973	.969	.961
.02	.962	.965	.967	.967	.965	.961	.955	.948	.941	.927
.03	.943	.949	.951	.951	.949	.943	.935	.926	.916	.898
.04	.926	.933	.936	.936	.934	.926	.916	.905	.894	.872
.05	.909	.918	.922	.922	.920	.911	.899	.886	.874	.850
.06	.893	.903	.908	.909	.906	.896	.883	.869	.856	.830
.07	.877	.889	.895	.896	.893	.882	.868	.853	.839	.812
.08	.862	.876	.882	.883	.881	.869	.854	.839	.823	.795
.09	.847	.863	.870	.871	.869	.857	.841	.825	.809	.781
.10	.833	.850	.858	.860	.858	.845	.829	.812	.797	.767
.11	.820	.838	.847	.849	.847	.834	.818	.801	.784	.755
.12	.806	.826	.836	.838	.836	.824	.807	.790	.773	.744
.13	.794	.814	.825	.828	.826	.814	.797	.779	.763	.734
.14	.781	.803	.815	.819	.817	.804	.787	.770	.753	.724
.15	.769	.793	.805	.809	.807	.795	.778	.761	.744	.715
.16	.758	.782	.795	.800	.799	.786	.769	.752	.736	.707
.17	.746	.772	.786	.791	.790	.778	.761	.744	.728	.700
.18	.735	.762	.777	.782	.782	.770	.753	.736	.720	.693
.19	.725	.752	.768	.774	.774	.763	.746	.729	.713	.686
.20	.714	.743	.760	.767	.766	.755	.739	.722	.706	.679
.21	.704	.734	.752	.759	.759	.748	.732	.716	.700	.674
.22	.694	.726	.744	.751	.752	.741	.726	.709	.694	.668
.23	.685	.717	.736	.744	.745	.735	.720	.704	.688	.663
.24	.676	.709	.729	.737	.739	.729	.714	.698	.683	.658
.25	.667	.701	.722	.730	.732	.723	.708	.693	.678	.653
.26	.658	.693	.715	.724	.726	.717	.703	.688	.673	.649
.27	.649	.686	.708	.717	.720	.712	.698	.683	.668	.645
.28	.641	.678	.701	.711	.714	.707	.693	.678	.664	.641
.29	.633	.671	.695	.706	.709	.702	.688	.673	.660	.637
.30	.625	.664	.688	.700	.703	.697	.683	.669	.656	.633
.31	.617	.657	.682	.694	.698	.692	.679	.665	.652	.630
.32	.610	.651	.676	.689	.693	.687	.675	.661	.648	.627
.33	.602	.644	.670	.684	.688	.683	.671	.657	.645	.624
.34	.595	.638	.665	.678	.683	.678	.667	.654	.641	.621
.35	.588	.632	.659	.673	.678	.674	.663	.650	.638	.618
.36	.581	.626	.654	.668	.674	.670	.659	.647	.635	.615
.37	.575	.620	.648	.664	.669	.666	.655	.643	.632	.612
.38	.568	.614	.643	.659	.665	.662	.652	.640	.629	.610
.39	.562	.608	.638	.654	.661	.658	.649	.637	.626	.607
.40	.556	.603	.633	.650	.657	.655	.645	.634	.623	.605
.41	.549	.598	.629	.646	.653	.652	.642	.631	.621	.603

TABLE 80 (*Continued*)

FOR DETERMINING HYDRAULIC RADIUS, r, FOR TRAPEZOIDAL CHANNELS OF VARIOUS SIDE SLOPES

Let $x = \frac{\text{depth of water}}{\text{bottom width of channel}} = \frac{D}{b}$ and c_x = tabulated value. Then $r = c_xD$

x	Side slopes of channel, ratio of horizontal to vertical									
	Vertical	¼–1	½–1	¾–1	1–1	1½–1	2–1	2½–1	3–1	4–1
.42	.543	.592	.624	.641	.649	.648	.639	.629	.618	.600
.43	.538	.587	.619	.637	.645	.645	.636	.626	.616	.598
.44	.532	.582	.615	.633	.641	.642	.633	.623	.613	.596
.45	.526	.577	.611	.629	.638	.639	.631	.621	.611	.594
.46	.521	.572	.606	.626	.635	.636	.628	.618	.609	.592
.47	.515	.568	.602	.622	.631	.633	.625	.616	.607	.591
.48	.510	.563	.598	.618	.628	.630	.623	.614	.605	.589
.49	.505	.558	.594	.615	.625	.627	.620	.611	.603	.587
.50	.500	.554	.590	.611	.621	.624	.618	.609	.601	.586
.51	.495	.550	.587	.608	.618	.622	.616	.607	.599	.584
.52	.490	.545	.583	.604	.615	.619	.613	.605	.597	.583
.53	.485	.541	.579	.601	.612	.617	.611	.603	.595	.581
.54	.481	.537	.576	.598	.610	.614	.609	.601	.594	.580
.55	.476	.533	.572	.595	.607	.612	.607	.600	.592	.578
.56	.472	.529	.568	.592	.604	.610	.605	.598	.590	.577
.57	.467	.525	.565	.589	.601	.607	.603	.596	.589	.576
.58	.463	.521	.562	.586	.598	.605	.601	.594	.587	.574
.59	.459	.518	.558	.583	.595	.603	.599	.593	.586	.573
.60	.455	.514	.555	.580	.593	.601	.597	.591	.584	.572
.61	.450	.510	.552	.577	.591	.599	.596	.589	.583	.571
.62	.446	.507	.549	.575	.588	.597	.594	.588	.581	.569
.63	.442	.504	.546	.572	.586	.595	.592	.586	.580	.568
.64	.439	.500	.543	.569	.584	.593	.590	.585	.579	.567
.65	.435	.497	.540	.567	.581	.591	.589	.583	.577	.566
.66	.431	.494	.537	.564	.579	.589	.587	.582	.576	.565
.67	.427	.490	.534	.562	.577	.587	.586	.580	.575	.564
.68	.424	.487	.532	.559	.575	.585	.584	.579	.574	.563
.69	.420	.484	.529	.557	.573	.583	.583	.578	.573	.562
.70	.417	.481	.526	.555	.571	.582	.581	.577	.571	.561
.71	.413	.478	.524	.552	.569	.580	.580	.575	.570	.560
.72	.410	.475	.521	.550	.567	.578	.578	.574	.569	.559
.73	.407	.472	.518	.548	.565	.577	.577	.573	.568	.558
.74	.403	.469	.516	.546	.563	.575	.576	.572	.567	.558
.75	.400	.467	.514	.544	.561	.573	.574	.570	.566	.557
.76	.397	.464	.511	.542	.559	.572	.573	.569	.565	.556
.77	.394	.461	.509	.539	.557	.570	.572	.568	.564	.555
.78	.391	.458	.507	.537	.555	.569	.570	.567	.563	.554
.79	.388	.456	.504	.535	.554	.567	.569	.566	.562	.554
.80	.385	.453	.502	.533	.552	.566	.568	.565	.561	.553
.81	.382	.450	.500	.531	.550	.565	.567	.564	.560	.552
.82	.379	.448	.498	.530	.548	.564	.566	.563	.559	.551
.83	.376	.445	.495	.528	.547	.562	.565	.562	.558	.551

Table 80 (*Concluded*)

For Determining Hydraulic Radius, r, for Trapezoidal Channels of Various Side Slopes

Let $x = \frac{\text{depth of water}}{\text{bottom width of channel}} = \frac{D}{b}$ and c_x = tabulated value. Then $r = c_x D$

x	Side slopes of channel, ratio of horizontal to vertical									
	Vertical	¼–1	½–1	¾–1	1–1	1½–1	2–1	2½–1	3–1	4–1
.84	.373	.443	.493	.526	.545	.561	.563	.561	.558	.550
.85	.370	.441	.491	.524	.544	.560	.562	.560	.557	.549
.86	.368	.438	.489	.522	.542	.558	.561	.559	.556	.549
.87	.365	.436	.487	.520	.540	.557	.560	.558	.555	.548
.88	.362	.434	.485	.519	.539	.556	.559	.558	.554	.547
.89	.360	.431	.483	.517	.537	.555	.558	.557	.554	.547
.90	.357	.429	.481	.515	.536	.554	.557	.556	.553	.546
.91	.355	.427	.479	.514	.534	.552	.556	.555	.552	.546
.92	.352	.425	.478	.512	.533	.551	.555	.554	.551	.545
.93	.350	.423	.476	.511	.532	.550	.554	.553	.551	.544
.94	.347	.420	.474	.509	.530	.549	.553	.553	.550	.544
.95	.345	.418	.472	.507	.529	.548	.553	.552	.549	.543
.96	.342	.416	.470	.506	.528	.547	.552	.551	.549	.543
.97	.340	.414	.469	.504	.526	.546	.551	.550	.548	.542
.98	.338	.412	.467	.503	.525	.545	.550	.550	.547	.542
.99	.336	.410	.465	.501	.524	.544	.549	.549	.547	.541
1.00	.333	.408	.464	.500	.522	.543	.548	.548	.546	.541
1.01	.331	.406	.462	.499	.521	.542	.547	.547	.545	.540
1.02	.329	.404	.460	.497	.520	.541	.547	.547	.545	.540
1.03	.327	.403	.459	.496	.519	.540	.546	.546	.544	.539
1.04	.325	.401	.457	.494	.518	.539	.545	.545	.544	.539
1.05	.323	.399	.456	.493	.516	.538	.544	.545	.543	.538
1.06	.321	.397	.454	.492	.515	.537	.543	.544	.543	.538
1.07	.318	.395	.452	.490	.514	.536	.543	.543	.542	.537
1.08	.316	.394	.451	.489	.513	.535	.542	.543	.541	.537
1.09	.314	.392	.449	.488	.512	.534	.541	.542	.541	.537
1.10	.312	.390	.448	.487	.511	.534	.541	.542	.540	.536
1.11	.311	.388	.446	.485	.510	.533	.540	.541	.540	.536
1.12	.309	.387	.445	.484	.509	.532	.539	.540	.539	.535
1.13	.307	.385	.444	.483	.508	.531	.539	.540	.539	.535
1.14	.305	.384	.442	.482	.507	.530	.538	.539	.538	.535
1.15	.303	.382	.441	.481	.506	.529	.537	.539	.538	.534
1.16	.301	.380	.440	.479	.505	.529	.537	.538	.537	.534
1.17	.299	.379	.438	.478	.504	.528	.536	.538	.537	.533
1.18	.298	.377	.437	.477	.503	.527	.535	.537	.536	.533
1.19	.296	.376	.436	.476	.502	.526	.535	.537	.536	.533
1.20	.294	.374	.434	.475	.501	.526	.534	.536	.536	.532
1.21	.292	.373	.433	.474	.500	.525	.533	.536	.535	.532
1.22	.291	.371	.432	.473	.499	.524	.533	.535	.535	.532
1.23	.289	.370	.431	.472	.498	.523	.532	.535	.534	.531
1.24	.287	.368	.429	.471	.497	.523	.532	.534	.534	.531
1.25	.286	.367	.428	.470	.496	.522	.531	.534	.533	.531

TABLE 81.—VALUES OF nv CORRESPONDING TO DIFFERENT VALUES OF r AND s IN MANNING'S FORMULA, $v = \frac{1.486}{n} r^{2/3} s^{1/2}$

To determine v, divide the tabulated valves by n

s = slope	r = hydraulic radius in feet									
	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
.00005	.0023	.0036	.0047	.0057	.0066	.0075	.0083	.0091	.0098	.0105
10	.0032	.0051	.0067	.0081	.0094	.0106	.0117	.0128	.0139	.0149
15	.0039	.0062	.0082	.0099	.0115	.0130	.0144	.0157	.0170	.0182
20	.0045	.0072	.0094	.0114	.0132	.0150	.0166	.0181	.0196	.0210
25	.0051	.0080	.0105	.0128	.0148	.0167	.0185	.0203	.0219	.0235
.00030	.0056	.0088	.0115	.0140	.0162	.0183	.0203	.0222	.0240	.0257
35	.0060	.0095	.0125	.0151	.0175	.0198	.0219	.0240	.0259	.0278
40	.0064	.0102	.0133	.0161	.0187	.0211	.0234	.0256	.0277	.0297
45	.0068	.0108	.0141	.0171	.0199	.0224	.0249	.0272	.0294	.0316
50	.0072	.0114	.0149	.0180	.0209	.0236	.0262	.0286	.0310	.0332
.00055	.0075	.0119	.0156	.0189	.0220	.0248	.0275	.0300	.0325	.0349
60	.0078	.0125	.0163	.0198	.0229	.0259	.0287	.0314	.0339	.0364
65	.0082	.0130	.0170	.0206	.0239	.0270	.0299	.0327	.0353	.0379
70	.0085	.0135	.0176	.0213	.0248	.0280	.0310	.0339	.0367	.0393
75	.0088	.0139	.0182	.0221	.0256	.0290	.0321	.0351	.0379	.0407
.00080	.0091	.0144	.0188	.0228	.0265	.0299	.0331	.0362	.0392	.0420
85	.0093	.0148	.0194	.0235	.0273	.0308	.0342	.0374	.0404	.0433
90	.0096	.0153	.0200	.0242	.0281	.0317	.0351	.0384	.0416	.0446
95	.0099	.0157	.0205	.0249	.0289	.0326	.0361	.0395	.0427	.0458
100	.0101	.0161	.0211	.0255	.0296	.0334	.0370	.0405	.0439	.0470
.0011	.0106	.0169	.0221	.0268	.0311	.0351	.0389	.0425	.0459	.0493
12	.0111	.0176	.0231	.0280	.0324	.0366	.0406	.0444	.0480	.0515
13	.0115	.0183	.0240	.0291	.0338	.0381	.0422	.0462	.0500	.0536
14	.0119	.0190	.0249	.0302	.0350	.0395	.0438	.0479	.0518	.0556
15	.0124	.0197	.0258	.0312	.0363	.0410	.0454	.0496	.0537	.0576
.0016	.0128	.0203	.0266	.0323	.0375	.0423	.0469	.0512	.0554	.0594
17	.0132	.0210	.0275	.0333	.0387	.0436	.0483	.0528	.0571	.0613
18	.0136	.0216	.0283	.0342	.0397	.0449	.0497	.0543	.0587	.0630
19	.0140	.0222	.0290	.0352	.0409	.0461	.0511	.0558	.0604	.0648
20	.0143	.0227	.0298	.0361	.0419	.0473	.0524	.0573	.0620	.0665
.0025	.0160	.0254	.0333	.0403	.0468	.0529	.0586	.0641	.0693	.0743
30	.0175	.0278	.0365	.0442	.0513	.0579	.0642	.0702	.0759	.0814
35	.0189	.0301	.0394	.0477	.0554	.0625	.0693	.0758	.0820	.0879
40	.0202	.0321	.0421	.0510	.0592	.0669	.0741	.0810	.0876	.0940
45	.0215	.0341	.0447	.0541	.0628	.0709	.0786	.0859	.0929	.0997
.0050	.0226	.0359	.0471	.0570	.0662	.0748	.0828	.0906	.0980	.1051
55	.0237	.0377	.0494	.0598	.0694	.0784	.0869	.0950	.1027	.1102
60	.0248	.0394	.0516	.0625	.0725	.0819	.0908	.0992	.1073	.1151
65	.0258	.0410	.0537	.0650	.0755	.0852	.0945	.1033	.1117	.1198
70	.0268	.0425	.0557	.0675	.0783	.0884	.0980	.1071	.1159	.1243
.0075	.0277	.0440	.0577	.0699	.0811	.0916	.1015	.1109	.1200	.1287
80	.0286	.0455	.0596	.0722	.0837	.0946	.1048	.1145	.1239	.1329
85	.0295	.0469	.0614	.0744	.0863	.0975	.1080	.1181	.1277	.1370
90	.0304	.0482	.0632	.0765	.0888	.1003	.1111	.1215	.1314	.1410
95	.0312	.0495	.0649	.0786	.0912	.1030	.1142	.1248	.1350	.1448
.0100	.0320	.0508	.0666	.0807	.0936	.1057	.1172	.1281	.1385	.1486

TABLE 81 (*Continued*)

VALUES OF nv CORRESPONDING TO DIFFERENT VALUES OF r AND s IN MANNING'S FORMULA, $v = \frac{1.486}{n} r^{2/3} s^{1/2}$

To determine v, divide the tabulated values by n

s = slope	r = hydraulic radius in feet									
	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0
.00005	.0112	.0119	.0125	.0132	.0138	.0144	.0150	.0156	.0161	.0167
10	.0158	.0168	.0177	.0186	.0195	.0203	.0212	.0220	.0228	.0236
15	.0194	.0206	.0217	.0228	.0239	.0249	.0259	.0269	.0279	.0289
20	.0224	.0237	.0250	.0263	.0275	.0288	.0299	.0311	.0322	.0334
25	.0250	.0265	.0280	.0294	.0308	.0321	.0335	.0348	.0360	.0373
.00030	.0274	.0291	.0307	.0322	.0337	.0352	.0367	.0381	.0395	.0409
35	.0296	.0314	.0331	.0348	.0364	.0380	.0396	.0411	.0427	.0441
40	.0317	.0336	.0354	.0372	.0389	.0407	.0423	.0440	.0456	.0472
45	.0336	.0356	.0376	.0395	.0413	.0431	.0449	.0467	.0484	.0500
50	.0354	.0375	.0396	.0416	.0435	.0454	.0473	.0492	.0510	.0528
.00055	.0371	.0394	.0415	.0436	.0457	.0477	.0496	.0516	.0535	.0553
60	.0388	.0411	.0434	.0456	.0477	.0498	.0519	.0539	.0558	.0578
65	.0405	.0428	.0451	.0474	.0497	.0518	.0540	.0561	.0581	.0601
70	.0419	.0444	.0468	.0492	.0515	.0538	.0560	.0582	.0603	.0624
75	.0434	.0460	.0485	.0509	.0533	.0556	.0580	.0602	.0624	.0646
.00080	.0448	.0475	.0501	.0526	.0551	.0575	.0599	.0622	.0645	.0667
85	.0462	.0489	.0516	.0542	.0568	.0593	.0617	.0641	.0665	.0688
90	.0475	.0503	.0531	.0558	.0584	.0610	.0635	.0660	.0684	.0708
95	.0488	.0517	.0546	.0573	.0600	.0627	.0653	.0678	.0703	.0727
100	.0501	.0531	.0560	.0588	.0616	.0643	.0669	.0695	.0721	.0746
.0011	.0525	.0557	.0587	.0617	.0646	.0674	.0702	.0729	.0756	.0782
12	.0549	.0581	.0613	.0644	.0675	.0704	.0733	.0762	.0790	.0817
13	.0571	.0605	.0638	.0671	.0702	.0733	.0763	.0793	.0822	.0851
14	.0593	.0628	.0662	.0696	.0729	.0761	.0792	.0823	.0853	.0883
15	.0613	.0650	.0686	.0720	.0754	.0787	.0820	.0852	.0883	.0914
.0016	.0633	.0671	.0708	.0744	.0779	.0813	.0847	.0880	.0912	.0944
17	.0653	.0692	.0730	.0767	.0803	.0838	.0873	.0907	.0940	.0973
18	.0672	.0712	.0751	.0789	.0826	.0862	.0898	.0933	.0967	.1001
19	.0690	.0732	.0772	.0811	.0849	.0886	.0923	.0959	.0994	.1028
20	.0708	.0751	.0792	.0832	.0871	.0909	.0947	.0984	.1020	.1055
.0025	.0792	.0839	.0885	.0930	.0974	.1016	.1058	.1099	.1140	.1180
30	.0867	.0919	.0970	.1019	.1067	.1113	.1159	.1204	.1249	.1292
35	.0937	.0993	.1047	.1100	.1152	.1203	.1252	.1301	.1349	.1396
40	.1001	.1061	.1119	.1176	.1231	.1286	.1339	.1391	.1442	.1492
45	.1062	.1126	.1188	.1248	.1306	.1364	.1420	.1475	.1529	.1582
.0050	.1120	.1187	.1252	.1315	.1377	.1438	.1497	.1555	.1612	.1668
55	.1174	.1245	.1313	.1379	.1444	.1508	.1570	.1631	.1691	.1749
60	.1227	.1300	.1371	.1441	.1509	.1575	.1640	.1703	.1766	.1827
65	.1277	.1353	.1427	.1499	.1570	.1639	.1707	.1773	.1838	.1902
70	.1325	.1404	.1481	.1556	.1629	.1701	.1771	.1840	.1908	.1974
.0075	.1371	.1453	.1533	.1611	.1687	.1761	.1833	.1904	.1974	.2043
80	.1416	.1501	.1583	.1664	.1742	.1818	.1893	.1967	.2039	.2110
85	.1460	.1547	.1632	.1715	.1795	.1874	.1952	.2027	.2102	.2175
90	.1502	.1592	.1679	.1764	.1847	.1929	.2008	.2086	.2163	.2238
95	.1544	.1636	.1726	.1813	.1898	.1981	.2063	.2143	.2222	.2299
.0100	.1584	.1678	.1770	.1860	.1947	.2033	.2117	.2199	.2280	.2359

TABLE 81 (*Continued*)

VALUES OF nv CORRESPONDING TO DIFFERENT VALUES OF r AND s IN MANNING'S FORMULA, $v = \frac{1.486}{n} r^{2/3} s^{1/2}$

To determine v, divide the tabulated values by n

s = slope	r = hydraulic radius in feet									
	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3.0
.00005	.0172	.0178	.0183	.0188	.0194	.0199	.0204	.0209	.0214	.0219
10	.0244	.0251	.0259	.0266	.0274	.0281	.0288	.0295	.0302	.0309
15	.0299	.0308	.0317	.0326	.0335	.0344	.0353	.0362	.0370	.0379
20	.0345	.0356	.0366	.0377	.0387	.0397	.0407	.0417	.0427	.0437
25	.0385	.0397	.0409	.0421	.0433	.0444	.0456	.0467	.0478	.0489
.00030	.0422	.0435	.0449	.0462	.0474	.0487	.0499	.0511	.0523	.0535
35	.0456	.0470	.0484	.0498	.0512	.0526	.0539	.0552	.0565	.0578
40	.0487	.0503	.0518	.0533	.0548	.0562	.0576	.0590	.0604	.0618
45	.0517	.0533	.0549	.0565	.0581	.0596	.0611	.0626	.0641	.0656
50	.0545	.0562	.0579	.0596	.0612	.0628	.0644	.0660	.0676	.0691
.00055	.0572	.0590	.0607	.0625	.0642	.0659	.0676	.0692	.0709	.0725
60	.0596	.0616	.0634	.0653	.0671	.0688	.0706	.0723	.0740	.0757
65	.0621	.0641	.0660	.0679	.0698	.0716	.0735	.0753	.0771	.0788
70	.0645	.0665	.0685	.0705	.0724	.0743	.0762	.0781	.0800	.0818
75	.0667	.0688	.0709	.0730	.0750	.0770	.0789	.0809	.0828	.0847
.00080	.0689	.0711	.0732	.0753	.0774	.0795	.0815	.0835	.0855	.0874
85	.0711	.0733	.0755	.0777	.0798	.0819	.0840	.0861	.0881	.0901
90	.0731	.0754	.0777	.0799	.0821	.0843	.0864	.0886	.0907	.0927
95	.0751	.0775	.0798	.0821	.0844	.0866	.0888	.0910	.0931	.0953
100	.0771	.0795	.0819	.0842	.0866	.0889	.0911	.0934	.0956	.0978
.0011	.0808	.0834	.0859	.0884	.0908	.0932	.0956	.0979	.1002	.1025
12	.0844	.0871	.0897	.0923	.0948	.0973	.0998	.1023	.1047	.1071
13	.0879	.0906	.0934	.0960	.0987	.1013	.1039	.1064	.1090	.1115
14	.0912	.0941	.0969	.0997	.1024	.1051	.1078	.1105	.1131	.1157
15	.0944	.0974	.1003	.1032	.1060	.1088	.1116	.1143	.1170	.1197
.0016	.0975	.1006	.1036	.1066	.1095	.1124	.1153	.1181	.1209	.1236
17	.1005	.1036	.1068	.1098	.1129	.1159	.1188	.1218	.1246	.1274
18	.1034	.1066	.1099	.1130	.1161	.1192	.1222	.1252	.1282	.1311
19	.1062	.1096	.1129	.1161	.1193	.1225	.1256	.1287	.1317	.1347
20	.1090	.1124	.1158	.1191	.1224	.1257	.1289	.1320	.1352	.1382
.0025	.1218	.1257	.1295	.1332	.1369	.1405	.1441	.1476	.1511	.1546
30	.1335	.1377	.1418	.1459	.1499	.1539	.1578	.1617	.1655	.1693
35	.1442	.1487	.1532	.1576	.1619	.1662	.1705	.1747	.1788	.1829
40	.1541	.1590	.1638	.1685	.1731	.1777	.1822	.1867	.1911	.1955
45	.1635	.1686	.1737	.1787	.1836	.1885	.1933	.1980	.2027	.2074
.0050	.1723	.1777	.1831	.1884	.1936	.1987	.2037	.2087	.2137	.2186
55	.1807	.1864	.1920	.1976	.2030	.2084	.2137	.2189	.2241	.2292
60	.1888	.1947	.2006	.2063	.2120	.2177	.2232	.2287	.2341	.2394
65	.1965	.2027	.2088	.2148	.2207	.2265	.2323	.2380	.2436	.2492
70	.2039	.2103	.2166	.2229	.2290	.2351	.2411	.2470	.2528	.2586
.0075	.2110	.2177	.2242	.2307	.2371	.2433	.2495	.2557	.2617	.2677
80	.2180	.2248	.2316	.2383	.2448	.2513	.2577	.2640	.2703	.2765
85	.2247	.2317	.2397	.2456	.2524	.2591	.2657	.2722	.2786	.2850
90	.2312	.2385	.2456	.2527	.2597	.2666	.2734	.2801	.2867	.2932
95	.2375	.2450	.2524	.2596	.2668	.2739	.2808	.2877	.2946	.3013
.0100	.2437	.2514	.2589	.2664	.2737	.2810	.2881	.2952	.3022	.3091

TABLE 81 (*Continued*)

VALUES OF nv CORRESPONDING TO DIFFERENT VALUES OF r AND s IN MANNING'S FORMULA, $v = \frac{1.486}{n} r^{2/3} s^{1/2}$

To determine v, divide the tabulated values by n

s = slope	r = hydraulic radius in feet									
	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9	4.0
.00005	.0223	.0228	.0233	.0238	.0242	.0247	.0251	.0256	.0260	.0265
10	.0316	.0323	.0329	.0336	.0343	.0349	.0356	.0362	.0368	.0374
15	.0387	.0395	.0403	.0412	.0420	.0428	.0435	.0443	.0451	.0459
20	.0447	.0456	.0466	.0475	.0484	.0494	.0503	.0512	.0521	.0530
25	.0500	.0510	.0521	.0531	.0542	.0552	.0562	.0572	.0582	.0592
.00030	.0547	.0559	.0571	.0582	.0593	.0605	.0616	.0627	.0638	.0649
35	.0591	.0604	.0616	.0629	.0641	.0653	.0665	.0677	.0689	.0701
40	.0632	.0645	.0659	.0672	.0685	.0698	.0711	.0724	.0736	.0749
45	.0670	.0685	.0699	.0713	.0727	.0741	.0754	.0768	.0781	.0794
50	.0706	.0722	.0737	.0751	.0766	.0781	.0795	.0809	.0823	.0837
.00055	.0741	.0757	.0773	.0788	.0803	.0819	.0834	.0849	.0864	.0878
60	.0774	.0791	.0807	.0823	.0839	.0855	.0871	.0886	.0902	.0917
65	.0806	.0823	.0840	.0857	.0873	.0890	.0906	.0923	.0939	.0955
70	.0836	.0854	.0872	.0889	.0906	.0924	.0941	.0957	.0974	.0991
75	.0865	.0884	.0902	.0920	.0938	.0956	.0974	.0991	.1008	.1026
.00080	.0894	.0913	.0932	.0950	.0969	.0987	.1005	.1024	.1041	.1059
85	.0921	.0941	.0960	.0980	.0999	.1018	.1036	.1055	.1073	.1092
90	.0948	.0968	.0988	.1008	.1028	.1047	.1066	.1086	.1105	.1123
95	.0974	.0995	.1015	.1036	.1056	.1076	.1096	.1115	.1135	.1154
100	.0999	.1021	.1042	.1063	.1083	.1104	.1124	.1144	.1164	.1184
.0011	.1048	.1070	.1093	.1114	.1136	.1158	.1179	.1200	.1221	.1242
12	.1094	.1118	.1141	.1164	.1137	.1209	.1231	.1254	.1275	.1297
13	.1139	.1164	.1188	.1212	.1235	.1259	.1282	.1305	.1328	.1350
14	.1182	.1207	.1232	.1257	.1282	.1306	.1330	.1354	.1378	.1401
15	.1224	.1250	.1276	.1301	.1327	.1352	.1377	.1401	.1426	.1450
.0016	.1264	.1291	.1318	.1344	.1370	.1396	.1422	.1447	.1473	.1498
17	.1303	.1331	.1358	.1385	.1412	.1439	.1466	.1492	.1518	.1544
18	.1340	.1369	.1397	.1426	.1453	.1481	.1508	.1535	.1562	.1589
19	.1377	.1407	.1436	.1465	.1493	.1522	.1550	.1577	.1605	.1633
20	.1413	.1443	.1473	.1503	.1532	.1561	.1590	.1618	.1647	.1675
.0025	.1580	.1614	.1647	.1680	.1713	.1745	.1777	.1809	.1841	.1872
30	.1730	.1768	.1804	.1840	.1876	.1912	.1947	.1982	.2017	.2051
35	.1869	.1909	.1949	.1988	.2027	.2065	.2103	.2141	.2178	.2215
40	.1998	.2041	.2083	.2125	.2167	.2208	.2248	.2289	.2329	.2368
45	.2119	.2165	.2210	.2254	.2298	.2342	.2385	.2427	.2470	.2512
.0050	.2234	.2282	.2329	.2376	.2422	.2468	.2514	.2559	.2603	.2648
55	.2343	.2393	.2443	.2492	.2541	.2589	.2636	.2684	.2731	.2777
60	.2447	.2500	.2552	.2603	.2654	.2704	.2754	.2803	.2852	.2901
65	.2548	.2602	.2656	.2709	.2762	.2814	.2866	.2917	.2968	.3019
70	.2643	.2700	.2756	.2811	.2866	.2920	.2974	.3028	.3080	.3133
.0075	.2736	.2795	.2852	.2910	.2967	.3023	.3079	.3134	.3189	.3242
80	.2826	.2886	.2946	.3005	.3064	.3122	.3180	.3237	.3293	.3349
85	.2913	.2975	.3037	.3098	.3158	.3218	.3277	.3336	.3395	.3452
90	.2997	.3061	.3125	.3188	.3250	.3311	.3372	.3433	.3493	.3552
95	.3079	.3145	.3210	.3275	.3339	.3402	.3465	.3527	.3589	.3650
.0100	.3159	.3227	.3294	.3360	.3426	.3491	.3555	.3619	.3682	.3745

TABLE 81 (*Continued*)

VALUES OF nv CORRESPONDING TO DIFFERENT VALUES OF r AND s IN MANNING'S FORMULA, $v = \frac{1.486}{n} r^{2/3} s^{1/2}$

To determine v, divide the tabulated values by n

s = slope	r = hydraulic radius in feet									
	4.2	4.4	4.6	4.8	5.0	5.2	5.4	5.6	5.8	6.0
.00005	.0274	.0282	.0291	.0299	.0307	.0315	.0323	.0331	.0339	.0347
10	.0387	.0399	.0411	.0423	.0435	.0446	.0457	.0469	.0480	.0491
15	.0474	.0489	.0503	.0518	.0532	.0546	.0560	.0574	.0588	.0601
20	.0547	.0564	.0581	.0598	.0615	.0631	.0647	.0663	.0678	.0694
25	.0612	.0631	.0650	.0669	.0687	.0705	.0723	.0741	.0759	.0776
.00030	.0670	.0691	.0712	.0732	.0753	.0773	.0792	.0812	.0831	.0850
35	.0724	.0747	.0769	.0791	.0813	.0834	.0856	.0877	.0897	.0918
40	.0774	.0798	.0822	.0846	.0869	.0892	.0915	.0937	.0959	.0981
45	.0821	.0846	.0872	.0897	.0922	.0946	.0970	.0994	.1018	.1041
50	.0865	.0892	.0919	.0946	.0972	.0997	.1023	.1048	.1073	.1097
.00055	.0907	.0936	.0964	.0992	.1019	.1046	.1073	.1099	.1125	.1152
60	.0948	.0977	.1007	.1036	.1064	.1092	.1120	.1148	.1175	.1202
65	.0986	.1017	.1048	.1078	.1108	.1137	.1166	.1195	.1223	.1251
70	.1024	.1056	.1087	.1119	.1150	.1180	.1210	.1240	.1269	.1298
75	.1059	.1093	.1125	.1158	.1190	.1222	.1253	.1284	.1314	.1344
.00080	.1094	.1129	.1163	.1196	.1229	.1262	.1294	.1325	.1357	.1388
85	.1128	.1163	.1198	.1233	.1267	.1300	.1334	.1366	.1399	.1431
90	.1161	.1197	.1233	.1269	.1304	.1338	.1372	.1406	.1439	.1472
95	.1192	.1230	.1267	.1303	.1339	.1375	.1410	.1444	.1479	.1512
100	.1223	.1262	.1300	.1337	.1374	.1410	.1446	.1482	.1517	.1553
.0011	.1283	.1323	.1363	.1402	.1441	.1479	.1517	.1554	.1591	.1627
12	.1340	.1382	.1424	.1465	.1505	.1545	.1584	.1623	.1662	.1700
13	.1395	.1439	.1482	.1525	.1567	.1608	.1649	.1690	.1730	.1769
14	.1447	.1493	.1538	.1582	.1626	.1669	.1711	.1753	.1795	.1836
15	.1498	.1545	.1592	.1638	.1683	.1727	.1771	.1815	.1858	.1900
.0016	.1547	.1596	.1644	.1691	.1738	.1784	.1830	.1874	.1919	.1963
17	.1595	.1645	.1695	.1743	.1792	.1839	.1886	.1932	.1978	.2023
18	.1641	.1693	.1744	.1794	.1844	.1892	.1941	.1988	.2035	.2082
19	.1686	.1739	.1792	.1843	.1894	.1944	.1994	.2043	.2091	.2139
20	.1730	.1784	.1838	.1891	.1943	.1995	.2046	.2096	.2145	.2194
.0025	.1934	.1995	.2055	.2114	.2173	.2230	.2287	.2343	.2399	.2454
30	.2119	.2186	.2251	.2316	.2380	.2443	.2505	.2567	.2628	.2688
35	.2289	.2361	.2432	.2502	.2571	.2639	.2706	.2772	.2838	.2903
40	.2447	.2524	.2600	.2674	.2748	.2821	.2893	.2964	.3034	.3103
45	.2595	.2677	.2757	.2837	.2915	.2992	.3068	.3144	.3218	.3292
.0050	.2735	.2821	.2906	.2990	.3072	.3154	.3234	.3314	.3392	.3470
55	.2869	.2959	.3048	.3136	.3222	.3308	.3392	.3475	.3558	.3639
60	.2996	.3091	.3184	.3275	.3366	.3455	.3543	.3630	.3716	.3801
65	.3119	.3217	.3314	.3409	.3503	.3596	.3688	.3778	.3868	.3956
70	.3237	.3338	.3439	.3538	.3635	.3732	.3827	.3921	.4014	.4105
.0075	.3350	.3456	.3560	.3662	.3763	.3863	.3961	.4058		
80	.3460	.3569	.3676	.3782	.3886	.3989	.4091			
85	.3566	.3679	.3790	.3898	.4006					
90	.3670	.3785	.3899	.4012						
95	.3770	.3889	.4006							
.0100	.3868	.3990								

TABLE 81 (*Continued*)

VALUES OF nv CORRESPONDING TO DIFFERENT VALUES OF r AND s IN MANNING'S FORMULA, $v = \frac{1.486}{n} r^{2/3}s^{1/2}$

To determine v, divide the tabulated values by n

s = slope	r = hydraulic radius in feet									
	6.2	6.4	6.6	6.8	7.0	7.2	7.4	7.6	7.8	8.0
.00005	.0355	.0362	.0370	.0377	.0385	.0392	.0399	.0406	.0413	.0420
10	.0502	.0512	.0523	.0533	.0544	.0554	.0564	.0574	.0584	.0594
15	.0614	.0627	.0640	.0653	.0666	.0679	.0691	.0704	.0716	.0728
20	.0709	.0724	.0739	.0754	.0769	.0784	.0798	.0812	.0826	.0841
25	.0793	.0810	.0827	.0843	.0860	.0876	.0892	.0908	.0924	.0940
.00030	.0869	.0887	.0906	.0924	.0942	.0960	.0977	.0995	.1012	.1030
35	.0938	.0958	.0978	.0998	.1017	.1037	.1056	.1075	.1093	.1112
40	.1003	.1025	.1046	.1067	.1088	.1108	.1129	.1149	.1169	.1189
45	.1064	.1087	.1109	.1132	.1154	.1175	.1197	.1219	.1240	.1261
50	.1121	.1145	.1169	.1193	.1216	.1239	.1262	.1284	.1307	.1329
.00055	.1176	.1201	.1226	.1251	.1275	.1299	.1323	.1347	.1371	.1394
60	.1229	.1255	.1281	.1307	.1332	.1357	.1382	.1407	.1432	.1456
65	.1279	.1306	.1333	.1360	.1386	.1413	.1439	.1464	.1490	.1515
70	.1327	.1355	.1383	.1411	.1439	.1466	.1493	.1520	.1546	.1573
75	.1374	.1403	.1432	.1461	.1489	.1517	.1545	.1573	.1601	.1628
.00080	.1419	.1449	.1479	.1509	.1538	.1567	.1596	.1625	.1653	.1681
85	.1462	.1493	.1524	.1555	.1585	.1615	.1645	.1675	.1704	.1733
90	.1505	.1537	.1569	.1600	.1631	.1662	.1693	.1723	.1753	.1783
95	.1546	.1579	.1612	.1644	.1676	.1708	.1739	.1771	.1801	.1832
100	.1586	.1620	.1653	.1687	.1720	.1752	.1785	.1817	.1848	.1880
.0011	.1663	.1699	.1734	.1769	.1804	.1838	.1872	.1905	.1938	.1971
12	.1737	.1774	.1811	.1848	.1884	.1919	.1955	.1990	.2025	.2059
13	.1808	.1847	.1885	.1923	.1961	.1998	.2035	.2071	.2107	.2143
14	.1877	.1917	.1956	.1996	.2035	.2073	.2111	.2149	.2187	.2224
15	.1942	.1984	.2025	.2066	.2106	.2146	.2186	.2225	.2264	.2302
.0016	.2006	.2049	.2091	.2134	.2175	.2216	.2257	.2298	.2338	.2378
17	.2068	.2112	.2156	.2199	.2242	.2285	.2327	.2368	.2410	.2451
18	.2128	.2173	.2218	.2263	.2307	.2351	.2394	.2437	.2480	.2522
19	.2186	.2233	.2279	.2325	.2370	.2415	.2460	.2504	.2548	.2591
20	.2243	.2291	.2338	.2385	.2432	.2478	.2524	.2569	.2614	.2658
.0025	.2508	.2561	.2614	.2667	.2719	.2770	.2822	.2872	.2922	.2972
30	.2747	.2806	.2864	.2921	.2978	.3035	.3091	.3146	.3201	.3256
35	.2967	.3030	.3093	.3156	.3217	.3278	.3338	.3398	.3458	.3517
40	.3172	.3240	.3307	.3373	.3439	.3504	.3569	.3633	.3696	.3759
45	.3364	.3436	.3507	.3578	.3648	.3717	.3785	.3853	.3921	.3987
.0050	.3546	.3622	.3697	.3771	.3845	.3918	.3990	.4062	.4133	.4203
55	.3719	.3799	.3878	.3956	.4033	.4109	.4185			
60	.3885	.3968	.4050	.4132						
65	.4043	.4130								
70										

TABLE 81 (*Concluded*)

VALUES OF *nv* CORRESPONDING TO DIFFERENT VALUES OF r AND s IN MANNING'S FORMULA, $v = \frac{1.486}{n} r^{\frac{2}{3}} s^{\frac{1}{2}}$

To determine v, divide the tabulated values by n

s = slope	r = hydraulic radius in feet									
	8.2	8.4	8.6	8.8	9.0	9.2	9.4	9.6	9.8	10.0
.00005	.0427	.0434	.0441	.0448	.0455	.0461	.0468	.0475	.0481	.0488
10	.0604	.0614	.0624	.0633	.0643	.0653	.0662	.0671	.0681	.0690
15	.0740	.0752	.0764	.0776	.0787	.0799	.0811	.0822	.0833	.0845
20	.0855	.0868	.0882	.0896	.0909	.0923	.0936	.0949	.0962	.0975
25	.0955	.0971	.0986	.1002	.1017	.1032	.1047	.1061	.1076	.1091
.00030	.1047	.1064	.1080	.1097	.1114	.1130	.1146	.1163	.1179	.1195
35	.1131	.1149	.1167	.1185	.1203	.1221	.1238	.1256	.1273	.1290
40	.1209	.1228	.1248	.1267	.1286	.1305	.1324	.1343	.1361	.1380
45	.1282	.1303	.1323	.1344	.1364	.1384	.1404	.1424	.1444	.1463
50	.1351	.1373	.1395	.1416	.1438	.1459	.1480	.1501	.1522	.1542
.00055	.1417	.1440	.1463	.1485	.1508	.1530	.1552	.1574	.1596	.1618
60	.1480	.1504	.1528	.1552	.1575	.1598	.1621	.1644	.1667	.1690
65	.1541	.1566	.1590	.1615	.1639	.1664	.1687	.1711	.1735	.1759
70	.1599	.1625	.1650	.1676	.1701	.1726	.1751	.1776	.1801	.1825
75	.1655	.1682	.1708	.1735	.1761	.1787	.1813	.1838	.1864	.1889
.00080	.1709	.1737	.1764	.1792	.1819	.1845	.1872	.1899	.1925	.1951
85	.1762	.1790	.1819	.1847	.1875	.1902	.1930	.1957	.1984	.2011
90	.1813	.1842	.1871	.1900	.1929	.1957	.1986	.2014	.2042	.2069
95	.1863	.1893	.1923	.1952	.1982	.2011	.2040	.2069	.2098	.2126
100	.1911	.1942	.1973	.2003	.2033	.2063	.2093	.2123	.2152	.2181
.0011	.2004	.2037	.2069	.2101	.2133	.2164	.2195	.2226	.2257	.2288
12	.2093	.2127	.2161	.2194	.2227	.2260	.2293	.2325	.2357	.2389
13	.2179	.2214	.2249	.2284	.2318	.2352	.2386	.2420	.2454	.2487
14	.2261	.2298	.2334	.2370	.2406	.2441	.2477	.2512	.2546	.2581
15	.2340	.2378	.2416	.2453	.2490	.2527	.2563	.2600	.2636	.2671
.0016	.2417	.2456	.2495	.2534	.2572	.2610	.2648	.2685	.2722	.2759
17	.2491	.2532	.2572	.2612	.2651	.2690	.2729	.2768	.2806	.2844
18	.2564	.2605	.2646	.2687	.2728	.2768	.2808	.2848	.2887	.2926
19	.2634	.2677	.2719	.2761	.2803	.2844	.2885	.2926	.2966	.3007
20	.2702	.2746	.2790	.2833	.2875	.2918	.2960	.3002	.3044	.3085
.0025	.3021	.3070	.3119	.3167	.3215	.3262	.3309	.3356	.3403	.3449
30	.3310	.3363	.3417	.3469	.3522	.3574	.3625	.3676	.3727	.3778
35	.3575	.3633	.3690	.3747	.3804	.3860	.3916	.3971	.4026	.4081
40	.3822	.3884	.3945	.4006	.4066	.4127	.4186	.4245		
45	.4054	.4119	.4184							

TABLE 82.—VALUES OF $\frac{1}{2.2082 r^{4/3}}$ CORRESPONDING TO DIFFERENT VALUES OF r, FOR DETERMINING THE SLOPE OF OPEN CHANNELS BY MANNING'S FORMULA

To determine s, multiply the tabulated value corresponding to r by $(nv)^2$

r	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
.1	9.76	8.59	7.67	6.88	6.23	5.68	5.21	4.81	4.46	4.15
.2	3.87	3.63	3.41	3.22	3.04	2.88	2.73	2.60	2.47	2.36
.3	2.25	2.16	2.07	1.99	1.91	1.84	1.77	1.70	1.65	1.59
.4	1.54	1.49	1.44	1.40	1.35	1.31	1.28	1.24	1.20	1.17
.5	1.14	1.11	1.08	1.06	1.03	1.01	.981	.958	.936	.915
.6	.895	.875	.857	.839	.821	.804	.788	.772	.757	.743
.7	.729	.715	.702	.689	.677	.665	.653	.642	.631	.620
.8	.610	.600	.590	.581	.571	.562	.554	.545	.537	.529
.9	.521	.514	.506	.499	.492	.485	.478	.472	.465	.459
1.0	.453	.447	.441	.435	.430	.424	.419	.414	.409	.404
1.1	.399	.394	.389	.385	.380	.376	.372	.367	.363	.359
1.2	.355	.351	.347	.344	.340	.336	.333	.329	.326	.322
1.3	.319	.316	.313	.310	.307	.304	.301	.298	.295	.292
1.4	.289	.286	.284	.281	.279	.276	.273	.271	.269	.266
1.5	.264	.261	.259	.257	.255	.253	.250	.248	.246	.244
1.6	.242	.240	.238	.236	.234	.232	.230	.229	.227	.225
1.7	.223	.221	.220	.218	.216	.215	.213	.212	.210	.208
1.8	.207	.205	.204	.202	.201	.199	.198	.197	.195	.194
1.9	.192	.191	.190	.189	.187	.186	.185	.183	.182	.181
2.0	.180	.179	.177	.176	.175	.174	.173	.172	.171	.169
2.1	.168	.167	.166	.165	.164	.163	.162	.161	.160	.159
2.2	.158	.157	.156	.155	.155	.154	.153	.152	.151	.150
2.3	.149	.148	.147	.147	.146	.145	.144	.143	.143	.142
2.4	.141	.140	.139	.139	.138	.137	.136	.136	.135	.134
2.5	.133	.133	.132	.131	.131	.130	.129	.129	.128	.127
2.6	.127	.126	.125	.125	.124	.124	.123	.122	.122	.121
2.7	.120	.120	.119	.119	.118	.118	.117	.116	.116	.115
2.8	.115	.114	.114	.113	.113	.112	.112	.111	.111	.110
2.9	.109	.109	.108	.108	.108	.107	.107	.106	.106	.105
3.0	.105	.104	.104	.103	.103	.102	.102	.101	.101	.101
3.1	.1002	.0998	.0993	.0989	.0985	.0981	.0977	.0972	.0968	.0964
3.2	.0960	.0956	.0952	.0948	.0945	.0941	.0937	.0933	.0929	.0925
3.3	.0921	.0918	.0914	.0911	.0907	.0903	.0900	.0896	.0893	.0889
3.4	.0886	.0882	.0879	.0875	.0872	.0869	.0865	.0862	.0859	.0855
3.5	.0852	.0849	.0846	.0843	.0839	.0836	.0833	.0830	.0827	.0824
3.6	.0821	.0818	.0815	.0812	.0809	.0806	.0803	.0800	.0797	.0794
3.7	.0791	.0788	.0786	.0783	.0780	.0777	.0775	.0772	.0769	.0766
3.8	.0764	.0761	.0758	.0756	.0753	.0750	.0748	.0745	.0743	.0740
3.9	.0738	.0735	.0733	.0730	.0728	.0725	.0723	.0720	.0718	.0716
4.0	.0713	.0711	.0708	.0706	.0704	.0701	.0699	.0697	.0695	.0692
4.1	.0690	.0688	.0686	.0683	.0681	.0679	.0677	.0675	.0673	.0670
4.2	.0668	.0666	.0664	.0662	.0660	.0658	.0656	.0654	.0652	.0650
4.3	.0648	.0646	.0644	.0642	.0640	.0638	.0636	.0634	.0632	.0630
4.4	.0628	.0626	.0624	.0622	.0621	.0619	.0617	.0615	.0613	.0611
4.5	.0610	.0608	.0606	.0604	.0602	.0601	.0599	.0597	.0595	.0594
4.6	.0592	.0590	.0589	.0587	.0585	.0583	.0582	.0580	.0578	.0577
4.7	.0575	.0574	.0572	.0570	.0569	.0567	.0566	.0564	.0562	.0561
4.8	.0559	.0558	.0556	.0555	.0553	.0552	.0550	.0549	.0547	.0546
4.9	.0544	.0543	.0541	.0540	.0538	.0537	.0535	.0534	.0533	.0531
5.0	.0530	.0528	.0527	.0525	.0524	.0523	.0521	.0520	.0519	.0517

TABLE 82 (*Concluded*)

VALUES OF $\frac{1}{2.2082\,r^{1/3}}$ CORRESPONDING TO DIFFERENT VALUES OF r FOR DETERMINING THE SLOPE OF OPEN CHANNELS BY MANNING'S FORMULA

To determine s, multiply the tabulated value corresponding to r by $(nv)^2$

r	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
5	.0530	.0516	.0503	.0490	.0478	.0466	.0455	.0445	.0435	.0425
6	.0415	.0406	.0398	.0389	.0381	.0373	.0365	.0358	.0351	.0345
7	.0338	.0332	.0326	.0320	.0314	.0308	.0303	.0298	.0293	.0288
8	.0283	.0278	.0274	.0269	.0265	.0261	.0257	.0253	.0249	.0246
9	.0242	.0238	.0235	.0232	.0228	.0225	.0222	.0219	.0216	.0213
10	.0210	.0207	.0205	.0202	.0199	.0197	.0194	.0192	.0190	.0187
11	.0185	.0183	.0181	.0179	.0177	.0175	.0173	.0171	.0169	.0167
12	.0165	.0163	.0161	.0160	.0158	.0156	.0154	.0153	.0151	.0150
13	.0148	.0147	.0145	.0144	.0142	.0141	.0140	.0138	.0137	.0136
14	.0134	.0133	.0132	.0130	.0129	.0128	.0127	.0126	.0125	.0124
15	.01224	.01213	.01203	.01192	.01182	.01172	.01162	.01152	.01142	.01132
16	.01123	.01114	.01105	.01096	.01087	.01078	.01069	.01061	.01052	.01044
17	.01036	.01028	.01020	.01012	.01004	.00996	.00989	.00982	.00974	.00967
18	.00960	.00953	.00946	.00939	.00932	.00925	.00919	.00912	.00906	.00900
19	.00893	.00887	.00881	.00875	.00869	.00863	.00857	.00851	.00845	.00840
20	.00834	.00829	.00823	.00818	.00812	.00807	.00802	.00797	.00792	.00787
21	.00782	.00777	.00772	.00767	.00762	.00758	.00753	.00748	.00744	.00739
22	.00735	.00730	.00726	.00722	.00717	.00713	.00709	.00705	.00700	.00696
23	.00692	.00688	.00684	.00680	.00677	.00673	.00669	.00665	.00661	.00658
24	.00654	.00651	.00647	.00643	.00640	.00636	.00633	.00630	.00626	.00623
25	.00620	.00616	.00613	.00610	.00607	.00603	.00600	.00597	.00594	.00591
26	.00588	.00585	.00582	.00579	.00576	.00573	.00570	.00567	.00565	.00562
27	.00559	.00556	.00554	.00551	.00548	.00546	.00543	.00540	.00538	.00535
28	.00533	.00530	.00528	.00525	.00523	.00520	.00518	.00515	.00513	.00511
29	.00508	.00506	.00504	.00501	.00499	.00497	.00495	.00493	.00490	.00488
30	.00486	.00484	.00482	.00479	.00477	.00475	.00473	.00471	.00469	.00467
31	.00465	.00463	.00461	.00459	.00457	.00455	.00453	.00451	.00449	.00448
32	.00446	.00444	.00442	.00440	.00439	.00437	.00435	.00433	.00431	.00430
33	.00428	.00426	.00424	.00423	.00421	.00419	.00418	.00416	.00415	.00413
34	.00411	.00410	.00408	.00407	.00405	.00403	.00402	.00400	.00399	.00397
35	.00396	.00394	.00393	.00391	.00390	.00388	.00387	.00385	.00384	.00382
36	.00381	.00380	.00378	.00377	.00375	.00374	.00373	.00371	.00370	.00369
37	.00367	.00366	.00365	.00363	.00362	.00361	.00360	.00358	.00357	.00356
38	.00354	.00353	.00352	.00351	.00350	.00348	.00347	.00346	.00345	.00344
39	.00342	.00341	.00340	.00339	.00338	.00337	.00336	.00334	.00333	.00332
40	.00331	.00330	.00329	.00328	.00327	.00326	.00324	.00323	.00322	.00321
41	.00320	.00319	.00318	.00317	.00316	.00315	.00314	.00313	.00312	.00311
42	.00310	.00309	.00308	.00307	.00306	.00305	.00304	.00303	.00302	.00302
43	.00301	.00300	.00299	.00298	.00297	.00296	.00295	.00294	.00293	.00292
44	.00292	.00291	.00290	.00289	.00288	.00287	.00286	.00285	.00285	.00284
45	.00283	.00282	.00281	.00280	.00280	.00279	.00278	.00277	.00276	.00276
46	.00275	.00274	.00273	.00272	.00272	.00271	.00270	.00269	.00268	.00268
47	.00267	.00266	.00265	.00265	.00264	.00263	.00263	.00262	.00261	.00260
48	.00260	.00259	.00258	.00257	.00257	.00256	.00255	.00255	.00254	.00253
49	.00253	.00252	.00251	.00251	.00250	.00249	.00248	.00248	.00247	.00247
50	.00246	.00245	.00245	.00244	.00243	.00243	.00242	.00241	.00241	.00240
51	.00239	.00239	.00238	.00238	.00237	.00236	.00236	.00235	.00235	.00234
52	.00233	.00233	.00232	.00232	.00231	.00230	.00230	.00229	.00229	.00228
53	.00227	.00227	.00226	.00226	.00225	.00225	.00224	.00224	.00223	.00222
54	.00222	.00221	.00221	.00220	.00220	.00219	.00219	.00218	.00218	.00217

Table 83.—Square Roots of Decimal Numbers

Number	.---0	.---1	.---2	.---3	.---4	.---5	.---6	.---7	.---8	.---9
.00001	.003162	.003317	.003464	.003606	.003742	.003873	.004000	.004123	.004243	.004359
.00002	.004472	.004583	.004690	.004796	.004899	.005000	.005099	.005196	.005292	.005385
.00003	.005477	.005568	.005657	.005745	.005831	.005916	.006000	.006083	.006164	.006245
.00004	.006325	.006403	.006481	.006557	.006633	.006708	.006782	.006856	.006928	.007000
.00005	.007071	.007141	.007211	.007280	.007348	.007416	.007483	.007550	.007616	.007681
.00006	.007746	.007810	.007874	.007937	.008000	.008062	.008124	.008185	.008246	.008307
.00007	.008367	.008426	.008485	.008544	.008602	.008660	.008718	.008775	.008832	.008888
.00008	.008944	.009000	.009055	.009110	.009165	.009220	.009274	.009327	.009381	.009434
.00009	.009487	.009539	.009592	.009644	.009695	.009747	.009798	.009849	.009899	.009950
.00010	.010000	.010050	.010100	.010149	.010198	.010247	.010296	.010344	.010392	.010440
.0001	.01000	.01049	.01095	.01140	.01183	.01225	.01265	.01304	.01342	.01378
.0002	.01414	.01449	.01483	.01517	.01549	.01581	.01612	.01643	.01673	.01703
.0003	.01732	.01761	.01789	.01817	.01844	.01871	.01897	.01924	.01949	.01975
.0004	.02000	.02025	.02049	.02074	.02098	.02121	.02145	.02168	.02191	.02214
.0005	.02236	.02258	.02280	.02302	.02324	.02345	.02366	.02387	.02408	.02429
.0006	.02449	.02470	.02490	.02510	.02530	.02550	.02569	.02588	.02608	.02627
.0007	.02646	.02665	.02683	.02702	.02720	.02739	.02757	.02775	.02793	.02811
.0008	.02828	.02846	.02864	.02881	.02898	.02915	.02933	.02950	.02966	.02983
.0009	.03000	.03017	.03033	.03050	.03066	.03082	.03098	.03114	.03130	.03146
.0010	.03162	.03178	.03194	.03209	.03225	.03240	.03256	.03271	.03286	.03302
.001	.03162	.03317	.03464	.03606	.03742	.03873	.04000	.04123	.04243	.04359
.002	.04472	.04583	.04690	.04796	.04899	.05000	.05099	.05196	.05292	.05385
.003	.05477	.05568	.05657	.05745	.05831	.05916	.06000	.06083	.06164	.06245
.004	.06325	.06403	.06481	.06557	.06633	.06708	.06782	.06856	.06928	.07000
.005	.07071	.07141	.07211	.07280	.07348	.07416	.07483	.07550	.07616	.07681
.006	.07746	.07810	.07874	.07937	.08000	.08062	.08124	.08185	.08246	.08307
.007	.08367	.08426	.08485	.08544	.08602	.08660	.08718	.08775	.08832	.08888
.008	.08944	.09000	.09055	.09110	.09165	.09220	.09274	.09327	.09381	.09434
.009	.09487	.09539	.09592	.09644	.09695	.09747	.09798	.09849	.09899	.09950
.010	.10000	.10050	.10100	.10149	.10198	.10247	.10296	.10344	.10392	.10440
.01	.1000	.1049	.1095	.1140	.1183	.1225	.1265	.1304	.1342	.1378
.02	.1414	.1449	.1483	.1517	.1549	.1581	.1612	.1643	.1673	.1703
.03	.1732	.1761	.1789	.1817	.1844	.1871	.1897	.1924	.1949	.1975
.04	.2000	.2025	.2049	.2074	.2098	.2121	.2145	.2168	.2191	.2214
.05	.2236	.2258	.2280	.2302	.2324	.2345	.2366	.2387	.2408	.2429
.06	.2449	.2470	.2490	.2510	.2530	.2550	.2569	.2588	.2608	.2627
.07	.2646	.2665	.2683	.2702	.2720	.2739	.2757	.2775	.2793	.2811
.08	.2828	.2846	.2864	.2881	.2898	.2915	.2933	.2950	.2966	.2983
.09	.3000	.3017	.3033	.3050	.3066	.3082	.3098	.3114	.3130	.3146
.10	.3162	.3178	.3194	.3209	.3225	.3240	.3256	.3271	.3286	.3302

TABLE 84.—TWO-THIRDS POWERS OF NUMBERS

Number	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
.0	.000	.046	.074	.097	.117	.136	.153	.170	.186	.201
.1	.215	.229	.243	.256	.269	.282	.295	.307	.319	.331
.2	.342	.353	.364	.375	.386	.397	.407	.418	.428	.438
.3	.448	.458	.468	.477	.487	.497	.506	.515	.525	.534
.4	.543	.552	.561	.570	.578	.587	.596	.604	.613	.622
.5	.630	.638	.647	.655	.663	.671	.679	.687	.695	.703
.6	.711	.719	.727	.735	.743	.750	.758	.765	.773	.781
.7	.788	.796	.803	.811	.818	.825	.832	.840	.847	.855
.8	.862	.869	.876	.883	.890	.897	.904	.911	.918	.925
.9	.932	.939	.946	.953	.960	.966	.973	.980	.987	.993
1.0	1.000	1.007	1.013	1.020	1.027	1.033	1.040	1.046	1.053	1.059
1.1	1.065	1.072	1.078	1.085	1.091	1.097	1.104	1.110	1.117	1.123
1.2	1.129	1.136	1.142	1.148	1.154	1.160	1.167	1.173	1.179	1.185
1.3	1.191	1.197	1.203	1.209	1.215	1.221	1.227	1.233	1.239	1.245
1.4	1.251	1.257	1.263	1.269	1.275	1.281	1.287	1.293	1.299	1.305
1.5	1.310	1.316	1.322	1.328	1.334	1.339	1.345	1.351	1.357	1.362
1.6	1.368	1.374	1.379	1.385	1.391	1.396	1.402	1.408	1.413	1.419
1.7	1.424	1.430	1.436	1.441	1.447	1.452	1.458	1.463	1.469	1.474
1.8	1.480	1.485	1.491	1.496	1.502	1.507	1.513	1.518	1.523	1.529
1.9	1.534	1.539	1.545	1.550	1.556	1.561	1.566	1.571	1.577	1.582
2.0	1.587	1.593	1.598	1.603	1.608	1.613	1.619	1.624	1.629	1.634
2.1	1.639	1.645	1.650	1.655	1.660	1.665	1.671	1.676	1.681	1.686
2.2	1.691	1.697	1.702	1.707	1.712	1.717	1.722	1.727	1.732	1.737
2.3	1.742	1.747	1.752	1.757	1.762	1.767	1.772	1.777	1.782	1.787
2.4	1.792	1.797	1.802	1.807	1.812	1.817	1.822	1.827	1.832	1.837
2.5	1.842	1.847	1.852	1.857	1.862	1.867	1.871	1.876	1.881	1.886
2.6	1.891	1.896	1.900	1.905	1.910	1.915	1.920	1.925	1.929	1.934
2.7	1.939	1.944	1.949	1.953	1.958	1.963	1.968	1.972	1.977	1.982
2.8	1.987	1.992	1.996	2.001	2.006	2.010	2.015	2.020	2.024	2.029
2.9	2.034	2.038	2.043	2.048	2.052	2.057	2.062	2.066	2.071	2.075
3.0	2.080	2.085	2.089	2.094	2.099	2.103	2.108	2.112	2.117	2.122
3.1	2.126	2.131	2.135	2.140	2.144	2.149	2.153	2.158	2.163	2.167
3.2	2.172	2.176	2.180	2.185	2.190	2.194	2.199	2.203	2.208	2.212
3.3	2.217	2.221	2.226	2.230	2.234	2.239	2.243	2.248	2.252	2.257
3.4	2.261	2.265	2.270	2.274	2.279	2.283	2.288	2.292	2.296	2.301
3.5	2.305	2.310	2.314	2.318	2.323	2.327	2.331	2.336	2.340	2.345
3.6	2.349	2.353	2.358	2.362	2.366	2.371	2.375	2.379	2.384	2.388
3.7	2.392	2.397	2.401	2.405	2.409	2.414	2.418	2.422	2.427	2.431
3.8	2.435	2.439	2.444	2.448	2.452	2.457	2.461	2.465	2.469	2.474
3.9	2.478	2.482	2.486	2.490	2.495	2.499	2.503	2.507	2.511	2.516
4.0	2.520	2.524	2.528	2.532	2.537	2.541	2.545	2.549	2.553	2.558
4.1	2.562	2.566	2.570	2.574	2.579	2.583	2.587	2.591	2.595	2.599
4.2	2.603	2.607	2.611	2.616	2.620	2.624	2.628	2.632	2.636	2.640
4.3	2.644	2.648	2.653	2.657	2.661	2.665	2.669	2.673	2.677	2.681
4.4	2.685	2.689	2.693	2.698	2.702	2.706	2.710	2.714	2.718	2.722
4.5	2.726	2.730	2.734	2.738	2.742	2.746	2.750	2.754	2.758	2.762
4.6	2.766	2.770	2.774	2.778	2.782	2.786	2.790	2.794	2.798	2.802
4.7	2.806	2.810	2.814	2.818	2.822	2.826	2.830	2.834	2.838	2.842
4.8	2.846	2.850	2.854	2.858	2.862	2.865	2.869	2.873	2.877	2.881
4.9	2.885	2.889	2.893	2.897	2.901	2.904	2.908	2.912	2.916	2.920

Table 84 (*Concluded*)

Two-thirds Powers of Numbers

Number	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
5.0	2.924	2.928	2.932	2.936	2.940	2.944	2.947	2.951	2.955	2.959
5.1	2.963	2.967	2.971	2.975	2.979	2.982	2.986	2.990	2.994	2.998
5.2	3.001	3.005	3.009	3.013	3.017	3.021	3.024	3.028	3.032	3.036
5.3	3.040	3.044	3.047	3.051	3.055	3.059	3.063	3.067	3.070	3.074
5.4	3.078	3.082	3.086	3.089	3.093	3.097	3.101	3.105	3.108	3.112
5.5	3.116	3.120	3.123	3.127	3.131	3.135	3.138	3.142	3.146	3.150
5.6	3.154	3.157	3.161	3.165	3.169	3.172	3.176	3.180	3.184	3.187
5.7	3.191	3.195	3.198	3.202	3.206	3.210	3.213	3.217	3.221	3.224
5.8	3.228	3.232	3.236	3.239	3.243	3.247	3.250	3.254	3.258	3.261
5.9	3.265	3.269	3.273	3.276	3.280	3.284	3.287	3.291	3.295	3.298
6.0	3.302	3.306	3.309	3.313	3.317	3.320	3.324	3.328	3.331	3.335
6.1	3.339	3.342	3.346	3.350	3.353	3.357	3.360	3.364	3.368	3.371
6.2	3.375	3.379	3.382	3.386	3.389	3.393	3.397	3.400	3.404	3.408
6.3	3.411	3.415	3.418	3.422	3.426	3.429	3.433	3.436	3.440	3.444
6.4	3.447	3.451	3.454	3.458	3.461	3.465	3.469	3.472	3.476	3.479
6.5	3.483	3.486	3.490	3.494	3.497	3.501	3.504	3.508	3.511	3.515
6.6	3.519	3.522	3.526	3.529	3.533	3.536	3.540	3.543	3.547	3.550
6.7	3.554	3.558	3.561	3.565	3.568	3.572	3.575	3.579	3.582	3.586
6.8	3.589	3.593	3.596	3.600	3.603	3.607	3.610	3.614	3.617	3.621
6.9	3.624	3.628	3.631	3.635	3.638	3.642	3.645	3.649	3.652	3.656
7.0	3.659	3.663	3.666	3.670	3.673	3.677	3.680	3.684	3.687	3.691
7.1	3.694	3.698	3.701	3.705	3.708	3.712	3.715	3.718	3.722	3.725
7.2	3.729	3.732	3.736	3.739	3.742	3.746	3.749	3.753	3.756	3.760
7.3	3.763	3.767	3.770	3.773	3.777	3.780	3.784	3.787	3.791	3.794
7.4	3.797	3.801	3.804	3.808	3.811	3.814	3.818	3.821	3.825	3.828
7.5	3.832	3.835	3.838	3.842	3.845	3.849	3.852	3.855	3.859	3.862
7.6	3.866	3.869	3.872	3.876	3.879	3.883	3.886	3.889	3.893	3.896
7.7	3.899	3.903	3.906	3.910	3.913	3.916	3.920	3.923	3.926	3.930
7.8	3.933	3.937	3.940	3.943	3.947	3.950	3.953	3.957	3.960	3.963
7.9	3.967	3.970	3.973	3.977	3.980	3.983	3.987	3.990	3.993	3.997
8.0	4.000	4.003	4.007	4.010	4.013	4.017	4.020	4.023	4.027	4.030
8.1	4.033	4.037	4.040	4.043	4.047	4.050	4.053	4.057	4.060	4.063
8.2	4.066	4.070	4.073	4.076	4.080	4.083	4.086	4.090	4.093	4.096
8.3	4.099	4.103	4.106	4.109	4.113	4.116	4.119	4.122	4.126	4.129
8.4	4.132	4.136	4.139	4.142	4.145	4.149	4.152	4.155	4.159	4.162
8.5	4.165	4.168	4.172	4.175	4.178	4.181	4.185	4.188	4.191	4.194
8.6	4.198	4.201	4.204	4.207	4.211	4.214	4.217	4.220	4.224	4.227
8.7	4.230	4.233	4.237	4.240	4.243	4.246	4.249	4.253	4.256	4.259
8.8	4.262	4.266	4.269	4.272	4.275	4.279	4.282	4.285	4.288	4.291
8.9	4.295	4.298	4.301	4.304	4.307	4.311	4.314	4.317	4.320	4.324
9.0	4.327	4.330	4.333	4.336	4.340	4.343	4.346	4.349	4.352	4.356
9.1	4.359	4.362	4.365	4.368	4.372	4.375	4.378	4.381	4.384	4.387
9.2	4.391	4.394	4.397	4.400	4.403	4.407	4.410	4.413	4.416	4.419
9.3	4.422	4.426	4.429	4.432	4.435	4.438	4.441	4.445	4.448	4.451
9.4	4.454	4.457	4.460	4.464	4.467	4.470	4.473	4.476	4.479	4.482
9.5	4.486	4.489	4.492	4.495	4.498	4.501	4.504	4.508	4.511	4.514
9.6	4.517	4.520	4.523	4.526	4.530	4.533	4.536	4.539	4.542	4.545
9.7	4.548	4.551	4.555	4.558	4.561	4.564	4.567	4.570	4.573	4.576
9.8	4.580	4.583	4.586	4.589	4.592	4.595	4.598	4.601	4.604	4.608
9.9	4.611	4.614	4.617	4.620	4.623	4.626	4.629	4.632	4.635	4.639
10.0	4.642									

TABLE 85.—THREE-EIGHTHS POWERS OF NUMBERS

Number	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
.0	.00	.18	.23	.27	.30	.33	.35	.37	.39	.41
.1	.42	.44	.45	.47	.48	.49	.50	.51	.53	.54
.2	.55	.56	.57	.58	.59	.59	.60	.61	.62	.63
.3	.64	.65	.65	.66	.67	.67	.68	.69	.70	.70
.4	.71	.72	.72	.73	.74	.74	.75	.75	.76	.77
.5	.77	.78	.78	.79	.79	.80	.80	.81	.82	.82
.6	.83	.83	.84	.84	.85	.85	.86	.86	.87	.87
.7	.87	.88	.88	.89	.89	.90	.90	.91	.91	.92
.8	.92	.92	.93	.93	.94	.94	.94	.95	.95	.96
.9	.96	.97	.97	.97	.98	.98	.98	.99	.99	1.00
1.0	1.00	1.00	1.01	1.01	1.01	1.02	1.02	1.03	1.03	1.03
1.1	1.04	1.04	1.04	1.05	1.05	1.05	1.06	1.06	1.06	1.07
1.2	1.07	1.07	1.08	1.08	1.08	1.09	1.09	1.09	1.10	1.10
1.3	1.10	1.11	1.11	1.11	1.12	1.12	1.12	1.13	1.13	1.13
1.4	1.13	1.14	1.14	1.14	1.15	1.15	1.15	1.16	1.16	1.16
1.5	1.16	1.17	1.17	1.17	1.18	1.18	1.18	1.18	1.19	1.19
1.6	1.19	1.20	1.20	1.20	1.20	1.21	1.21	1.21	1.21	1.22
1.7	1.22	1.22	1.23	1.23	1.23	1.23	1.24	1.24	1.24	1.24
1.8	1.25	1.25	1.25	1.25	1.26	1.26	1.26	1.26	1.27	1.27
1.9	1.27	1.27	1.28	1.28	1.28	1.28	1.29	1.29	1.29	1.29
2.0	1.30	1.30	1.30	1.30	1.31	1.31	1.31	1.31	1.32	1.32
2.1	1.32	1.32	1.33	1.33	1.33	1.33	1.33	1.34	1.34	1.34
2.2	1.34	1.35	1.35	1.35	1.35	1.36	1.36	1.36	1.36	1.36
2.3	1.37	1.37	1.37	1.37	1.38	1.38	1.38	1.38	1.38	1.39
2.4	1.39	1.39	1.39	1.40	1.40	1.40	1.40	1.40	1.41	1.41
2.5	1.41	1.41	1.41	1.42	1.42	1.42	1.42	1.42	1.43	1.43
2.6	1.43	1.43	1.44	1.44	1.44	1.44	1.44	1.45	1.45	1.45
2.7	1.45	1.45	1.46	1.46	1.46	1.46	1.46	1.47	1.47	1.47
2.8	1.47	1.47	1.48	1.48	1.48	1.48	1.48	1.48	1.49	1.49
2.9	1.49	1.49	1.49	1.50	1.50	1.50	1.50	1.50	1.51	1.51
3.0	1.51	1.51	1.51	1.52	1.52	1.52	1.52	1.52	1.52	1.53
3.1	1.53	1.53	1.53	1.53	1.54	1.54	1.54	1.54	1.54	1.54
3.2	1.55	1.55	1.55	1.55	1.55	1.56	1.56	1.56	1.56	1.56
3.3	1.56	1.57	1.57	1.57	1.57	1.57	1.58	1.58	1.58	1.58
3.4	1.58	1.58	1.59	1.59	1.59	1.59	1.59	1.59	1.60	1.60
3.5	1.60	1.60	1.60	1.61	1.61	1.61	1.61	1.61	1.61	1.62
3.6	1.62	1.62	1.62	1.62	1.62	1.63	1.63	1.63	1.63	1.63
3.7	1.63	1.63	1.64	1.64	1.64	1.64	1.64	1.64	1.65	1.65
3.8	1.65	1.65	1.65	1.65	1.66	1.66	1.66	1.66	1.66	1.66
3.9	1.67	1.67	1.67	1.67	1.67	1.67	1.68	1.68	1.68	1.68
4.0	1.68	1.68	1.68	1.69	1.69	1.69	1.69	1.69	1.69	1.70
4.1	1.70	1.70	1.70	1.70	1.70	1.71	1.71	1.71	1.71	1.71
4.2	1.71	1.71	1.72	1.72	1.72	1.72	1.72	1.72	1.73	1.73
4.3	1.73	1.73	1.73	1.73	1.73	1.74	1.74	1.74	1.74	1.74
4.4	1.74	1.74	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.76
4.5	1.76	1.76	1.76	1.76	1.76	1.77	1.77	1.77	1.77	1.77
4.6	1.77	1.77	1.78	1.78	1.78	1.78	1.78	1.78	1.78	1.79
4.7	1.79	1.79	1.79	1.79	1.79	1.79	1.80	1.80	1.80	1.80
4.8	1.80	1.80	1.80	1.81	1.81	1.81	1.81	1.81	1.81	1.81
4.9	1.81	1.82	1.82	1.82	1.82	1.82	1.82	1.82	1.83	1.83

TABLE 85 (*Continued*)

THREE-EIGHTHS POWERS OF NUMBERS

Number	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
5.	1.83	1.84	1.86	1.87	1.88	1.89	1.91	1.92	1.93	1.94
6.	1.96	1.97	1.98	1.99	2.01	2.02	2.03	2.04	2.05	2.06
7.	2.07	2.09	2.10	2.11	2.12	2.13	2.14	2.15	2.16	2.17
8.	2.18	2.19	2.20	2.21	2.22	2.23	2.24	2.25	2.26	2.27
9.	2.28	2.29	2.30	2.31	2.32	2.33	2.34	2.34	2.35	2.36
10.	2.37	2.38	2.39	2.40	2.41	2.42	2.42	2.43	2.44	2.45
11.	2.46	2.46	2.47	2.48	2.49	2.50	2.51	2.52	2.52	2.53
12.	2.54	2.55	2.56	2.56	2.57	2.58	2.59	2.59	2.60	2.61
13.	2.62	2.62	2.63	2.64	2.65	2.65	2.66	2.67	2.68	2.68
14.	2.69	2.70	2.71	2.71	2.72	2.73	2.73	2.74	2.75	2.75
15.	2.76	2.77	2.77	2.78	2.79	2.79	2.80	2.81	2.81	2.82
16.	2.83	2.84	2.84	2.85	2.86	2.86	2.87	2.87	2.88	2.89
17.	2.89	2.90	2.91	2.91	2.92	2.93	2.93	2.94	2.94	2.95
18.	2.96	2.96	2.97	2.97	2.98	2.99	2.99	3.00	3.00	3.01
19.	3.02	3.02	3.03	3.03	3.04	3.05	3.05	3.06	3.06	3.07
20.	3.08	3.08	3.09	3.09	3.10	3.10	3.11	3.12	3.12	3.13
21.	3.13	3.14	3.14	3.15	3.15	3.16	3.17	3.17	3.18	3.18
22.	3.19	3.19	3.20	3.20	3.21	3.21	3.22	3.22	3.23	3.24
23.	3.24	3.25	3.25	3.26	3.26	3.27	3.27	3.28	3.28	3.29
24.	3.29	3.30	3.30	3.31	3.31	3.32	3.32	3.33	3.33	3.34
25.	3.34	3.35	3.35	3.36	3.36	3.37	3.37	3.38	3.38	3.39
26.	3.39	3.40	3.40	3.41	3.41	3.42	3.42	3.48	3.43	3.44
27.	3.44	3.45	3.45	3.46	3.46	3.47	3.47	3.47	3.48	3.48
28.	3.49	3.49	3.50	3.50	3.51	3.51	3.52	3.52	3.53	3.53
29.	3.54	3.54	3.54	3.55	3.55	3.56	3.56	3.57	3.57	3.58
30.	3.58	3.58	3.59	3.59	3.60	3.60	3.61	3.61	3.62	3.62
31.	3.62	3.63	3.63	3.64	3.64	3.65	3.65	3.66	3.66	3.66
32.	3.67	3.67	3.68	3.68	3.69	3.69	3.69	3.70	3.70	3.71
33.	3.71	3.72	3.72	3.72	3.73	3.73	3.74	3.74	3.74	3.75
34.	3.75	3.76	3.76	3.76	3.77	3.77	3.78	3.78	3.79	3.79
35.	3.79	3.80	3.80	3.81	3.81	3.81	3.82	3.82	3.83	3.83
36.	3.83	3.84	3.84	3.85	3.85	3.85	3.86	3.86	3.87	3.87
37.	3.87	3.88	3.88	3.89	3.89	3.89	3.90	3.90	3.91	3.91
38.	3.91	3.92	3.92	3.92	3.93	3.93	3.94	3.94	3.94	3.95
39.	3.95	3.95	3.96	3.96	3.97	3.97	3.97	3.98	3.98	3.98
40.	3.99	3.99	4.00	4.00	4.00	4.01	4.01	4.01	4.02	4.02
41.	4.03	4.03	4.03	4.04	4.04	4.04	4.05	4.05	4.05	4.06
42.	4.06	4.07	4.07	4.07	4.08	4.08	4.08	4.09	4.09	4.09
43.	4.10	4.10	4.10	4.11	4.11	4.12	4.12	4.12	4.13	4.13
44.	4.13	4.14	4.14	4.14	4.15	4.15	4.15	4.16	4.16	4.16
45.	4.17	4.17	4.18	4.18	4.18	4.19	4.19	4.19	4.20	4.20
46.	4.20	4.21	4.21	4.21	4.22	4.22	4.22	4.23	4.23	4.23
47.	4.24	4.24	4.24	4.25	4.25	4.25	4.26	4.26	4.26	4.27
48.	4.27	4.27	4.28	4.28	4.28	4.29	4.29	4.29	4.30	4.30
49	4.30	4.31	4.31	4.31	4.32	4.32	4.32	4.33	4.33	4.33
50.	4.34	4.34	4.34	4.35	4.35	4.35	4.36	4.36	4.36	4.37
51.	4.37	4.37	4.37	4.38	4.38	4.38	4.39	4.39	4.39	4.40
52.	4.40	4.40	4.41	4.41	4.41	4.42	4.42	4.42	4.43	4.43
53.	4.43	4.44	4.44	4.44	4.44	4.45	4.45	4.45	4.46	4.46
54.	4.46	4.47	4.47	4.47	4.48	4.48	4.48	4.48	4.49	4.49

TABLE 85 (*Concluded*)

THREE-EIGHTHS POWERS OF NUMBERS

Number	0	1	2	3	4	5	6	7	8	9
50.	4.34	4.37	4.40	4.43	4.46	4.49	4.52	4.55	4.58	4.61
60.	4.64	4.67	4.70	4.73	4.76	4.78	4.81	4.84	4.87	4.89
70.	4.92	4.95	4.97	5.00	5.02	5.05	5.07	5.10	5.12	5.15
80.	5.17	5.20	5.22	5.24	5.27	5.29	5.31	5.34	5.36	5.38
90.	5.41	5.43	5.45	5.47	5.49	5.52	5.54	5.56	5.58	5.60
100.	5.62	5.64	5.67	5.69	5.71	5.73	5.75	5.77	5.79	5.81
110.	5.83	5.85	5.87	5.89	5.91	5.93	5.95	5.96	5.98	6.00
120.	6.02	6.04	6.06	6.08	6.10	6.11	6.13	6.15	6.17	6.19
130.	6.20	6.22	6.24	6.26	6.28	6.29	6.31	6.33	6.35	6.36
140.	6.38	6.40	6.41	6.43	6.45	6.46	6.48	6.50	6.51	6.53
150.	6.55	6.56	6.58	6.60	6.61	6.63	6.64	6.66	6.68	6.69
160.	6.71	6.72	6.74	6.75	6.77	6.78	6.80	6.81	6.83	6.84
170.	6.86	6.87	6.89	6.90	6.92	6.93	6.95	6.96	6.98	6.99
180.	7.01	7.02	7.04	7.05	7.07	7.08	7.10	7.11	7.12	7.14
190.	7.15	7.17	7.18	7.20	7.21	7.22	7.24	7.25	7.27	7.28
200.	7.29	7.31	7.32	7.34	7.35	7.36	7.37	7.39	7.40	7.42
210.	7.43	7.44	7.46	7.47	7.48	7.50	7.51	7.52	7.54	7.55
220.	7.56	7.57	7.58	7.60	7.61	7.62	7.63	7.65	7.66	7.67
230.	7.69	7.70	7.71	7.72	7.73	7.75	7.76	7.77	7.78	7.80
240.	7.81	7.82	7.83	7.85	7.86	7.87	7.88	7.89	7.91	7.92
250.	7.93	7.94	7.95	7.96	7.98	7.99	8.00	8.01	8.02	8.04
260.	8.05	8.06	8.07	8.08	8.09	8.10	8.12	8.13	8.14	8.15
270.	8.16	8.17	8.18	8.20	8.21	8.22	8.23	8.24	8.25	8.26
280.	8.27	8.28	8.30	8.31	8.32	8.33	8.34	8.35	8.36	8.37
290.	8.38	8.39	8.40	8.42	8.43	8.44	8.45	8.46	8.47	8.48
300.	8.49	8.50	8.51	8.52	8.53	8.54	8.55	8.56	8.57	8.58
310.	8.60	8.61	8.62	8.63	8.64	8.65	8.66	8.67	8.68	8.69
320.	8.70	8.71	8.72	8.73	8.74	8.75	8.76	8.77	8.78	8.79
330.	8.80	8.81	8.82	8.83	8.84	8.85	8.86	8.87	8.88	8.89
340.	8.90	8.91	8.92	8.93	8.94	8.95	8.96	8.97	8.98	8.99
350.	9.00	9.01	9.01	9.02	9.03	9.04	9.05	9.06	9.07	9.08
360.	9.09	9.10	9.11	9.12	9.13	9.14	9.15	9.16	9.17	9.18
370.	9.18	9.19	9.20	9.21	9.22	9.23	9.24	9.25	9.26	9.27
380.	9.28	9.29	9.30	9.30	9.31	9.32	9.33	9.34	9.35	9.36
390.	9.37	9.38	9.39	9.40	9.40	9.41	9.42	9.43	9.44	9.45
400.	9.46	9.47	9.48	9.48	9.49	9.50	9.51	9.52	9.53	9.54
410.	9.55	9.55	9.56	9.57	9.58	9.59	9.60	9.61	9.61	9.62
420.	9.63	9.64	9.65	9.66	9.67	9.67	9.68	9.69	9.70	9.71
430.	9.72	9.73	9.73	9.74	9.75	9.76	9.77	9.78	9.78	9.79
440.	9.80	9.81	9.82	9.83	9.83	9.84	9.85	9.86	9.87	9.88
450.	9.88	9.89	9.90	9.91	9.92	9.93	9.93	9.94	9.95	9.96
460.	9.97	9.97	9.98	9.99	10.00	10.01	10.01	10.02	10.03	10.04
470.	10.05	10.06	10.06	10.07	10.08	10.09	10.09	10.10	10.11	10.12
480.	10.13	10.13	10.14	10.15	10.16	10.17	10.17	10.18	10.19	10.20
490.	10.21	10.21	10.22	10.23	10.24	10.24	10.25	10.26	10.27	10.28
500.	10.28	10.29	10.30	10.31	10.31	10.32	10.33	10.34	10.34	10.35
510.	10.36	10.37	10.37	10.38	10.39	10.40	10.41	10.41	10.42	10.43
520.	10.44	10.44	10.45	10.46	10.47	10.47	10.48	10.49	10.50	10.50
530.	10.51	10.52	10.52	10.53	10.54	10.55	10.55	10.56	10.57	10.58
540.	10.58	10.59	10.60	10.61	10.61	10.62	10.63	10.64	10.64	10.65

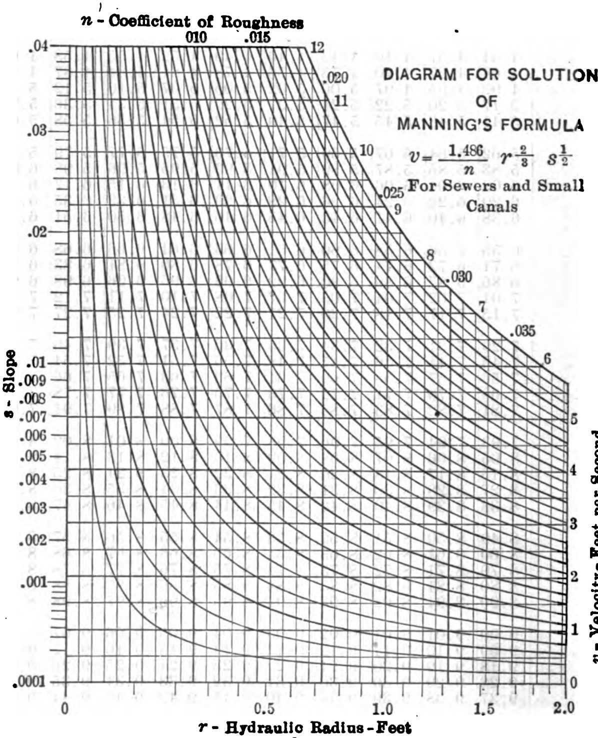
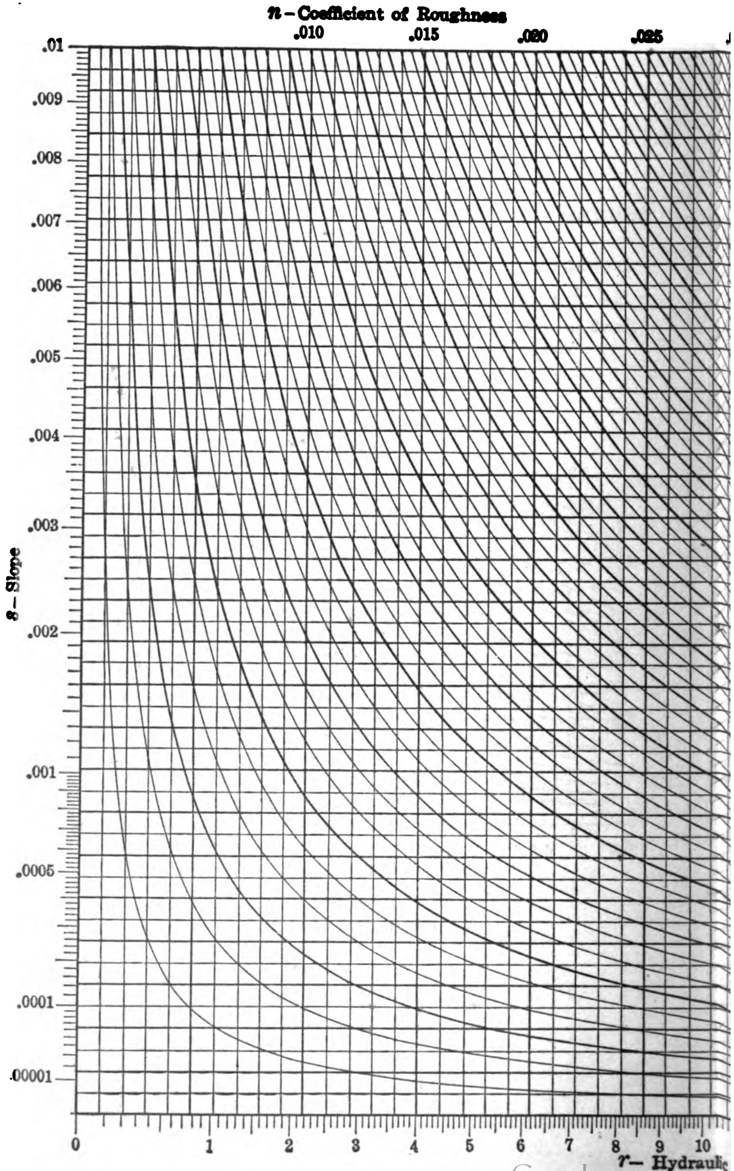


DIAGRAM 1.
(See note diagram 2.)

v - Velocity - Feet per Second



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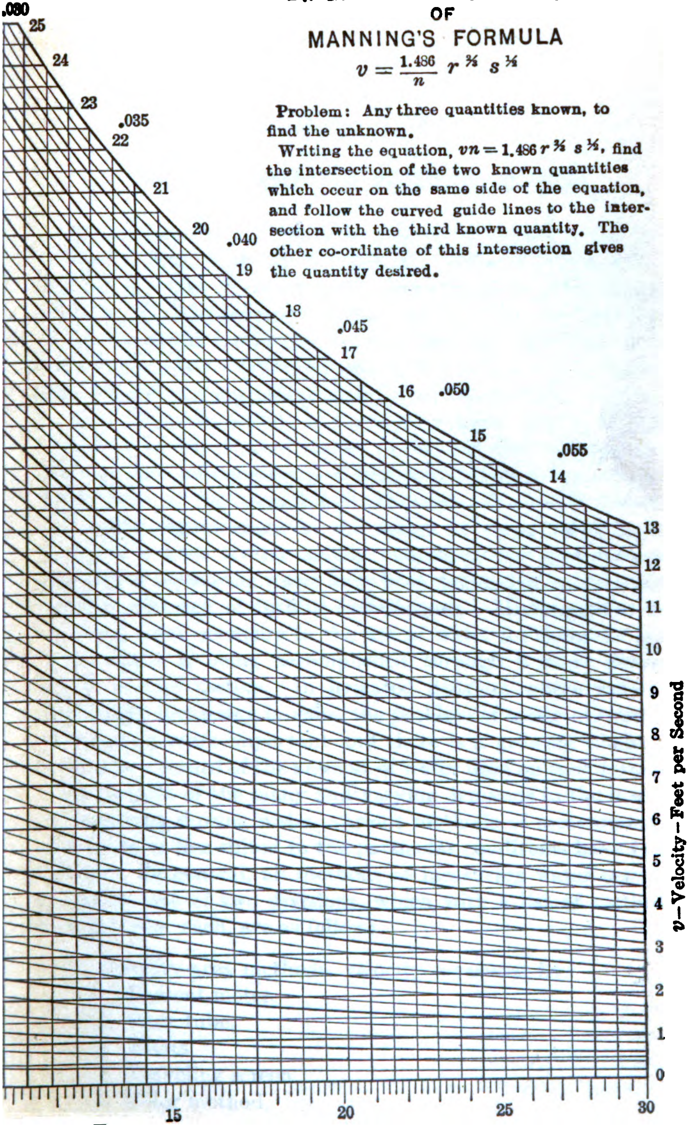
DIAG

DIAGRAM FOR SOLUTION
OF
MANNING'S FORMULA

$$v = \frac{1.486}{n} r^{2/3} s^{1/2}$$

Problem: Any three quantities known, to find the unknown.

Writing the equation, $vn = 1.486\, r^{2/3}\, s^{1/2}$, find the intersection of the two known quantities which occur on the same side of the equation, and follow the curved guide lines to the intersection with the third known quantity. The other co-ordinate of this intersection gives the quantity desired.



: Radius—Feet

RAM 2.

(Facing Page 2

CHAPTER VIII

MEASUREMENT OF FLOWING WATER

The measurement of flowing water is becoming a matter of increasing importance to the engineer. Both in the laboratory and in the field of practice the most accurate and effective methods of measurement are demanded. The determination of the empirical coefficients used in hydraulic formulas are all based upon actual measurements of flow and the reliability of these formulas is dependent upon the accuracy of such measurements. Continuous stream-discharge records, similar to those published by the United States Geological Survey, are based upon periodic measurements of flow, which records are an essential feature of the economic development of natural streams. The rapid improvement in the design of water turbines has produced a keen rivalry among manufacturers, and accurate methods of measuring water have been demanded for determining the efficiency of turbine installations. Municipalities are requiring more economy in the use of water for domestic purposes which is being accomplished through a more general use of service meters. In irrigated districts where water is continually increasing in value the problem of waste prevention is becoming more important and there is a growing tendency to require a record of the amount of water used on each farm.

On account of the many and varying demands in the matter of measuring flowing water, various methods of measurement, each more or less suited to the particular conditions, have been devised. In general, all methods of measuring water may be classed in one of two divisions, which, with a list of methods coming under each, are as follows:

(*a*) Velocity-area methods, velocity measured by:

1. Current meter.
2. Pitot tube.
3. Floats.
4. Traveling screen.
5. Color method.

(*b*) Direct-discharge methods;
1. Gravimetric.
2. Volumetric.
3. Weirs.
4. Orifices.
5. Meters.
6. Chemical gaging

Gravimetric and volumetric methods of measuring water, which require the determination of the weight or volume of water flowing in a given time, are adapted primarily to experimental work in laboratories or to the measurement of comparatively small quantities of water and will not be discussed. The methods of measuring water with orifices or weirs is explained in the chapters under these headings. The other methods listed above are explained in the following pages.

Velocity-area methods involve the determination of the mean velocity of the water, and with the cross-sectional area of the channel known the discharge equals the product of the two factors. The color and traveling screen methods provide for the determination of the mean velocity from a single observation. The current meter and Pitot tube give velocities in only one point in the cross-section at a time, and floats give the mean velocity in a limited area of the cross-section.

The current meter is generally preferred for measuring water in open channels, and is used almost exclusively for rivers. Before studying in detail the different methods of measurement a knowledge of the distribution of velocities in the cross-section of a channel is essential.

Distribution of Velocities

There is usually a noticeable lack of uniformity in the distribution of velocities in open channels and especially those of irregular section. The upper sketch in Fig. 66, reproduced from U. S. Geological Survey *Water Supply Paper* No. 305, is a typical example. The numbers in the cross-section indicate velocities in feet per second from which lines of equal velocity are drawn. In general, these lines follow quite well-defined laws which can be best understood from a study of vertical velocity curves.

Vertical velocity curves are obtained by taking velocities in a stream along a vertical line, beginning a few inches below the

surface and continuing at intervals of about 6 inches or 1 foot, the last velocity being taken as close to the bed of the stream as practicable. The velocities thus taken are plotted on cross-section paper with depths as ordinates and velocities as abscissas, a smooth curve being drawn as nearly as may be

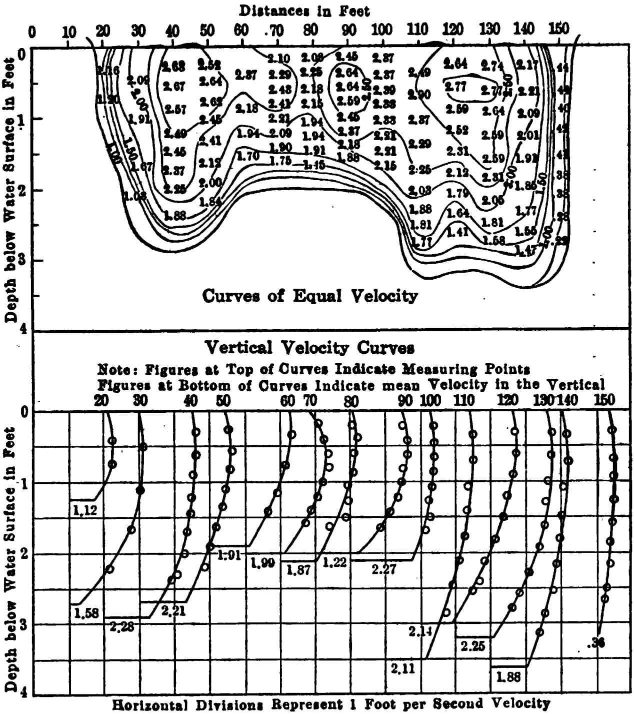


FIG. 66.—Distribution of velocities in open channel.

through these points. The velocity at any depth may then be scaled from this curve, the mean velocity being equal to the area included between the vertical axis and the curve and the horizontal lines at top and bottom of the curve, divided by the depth of water.

Fig. 66 shows examples of vertical velocity curves. Many such curves have been made by the United States Geological Survey for numerous streams, from a study of which the following fundamental principles have been deducted:

1. The maximum velocity occurs at a distance below the surface equal to about 5 to 25 per cent. of the depth of the stream, the per cent. increasing as the depth of the stream increases. For shallow streams with rough beds the thread of maximum velocity lies very near to the surface.

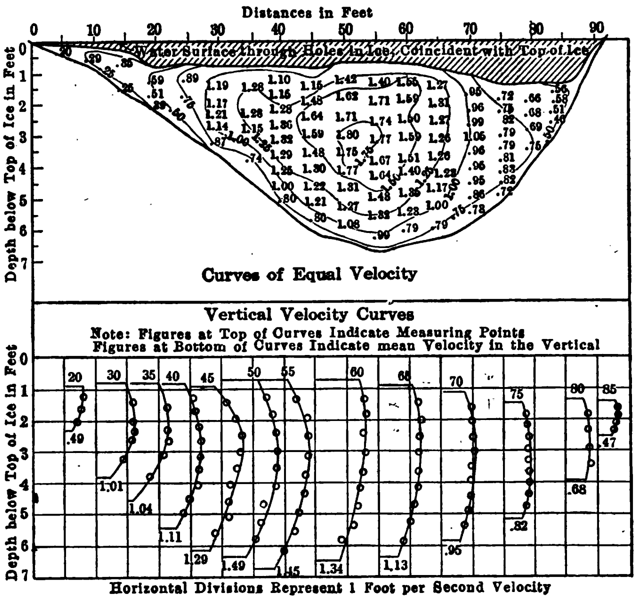


FIG. 67.—Distribution of velocities in ice-covered streams.

2. The vertical velocity curve approximates a parabola, whose axis is horizontal and passes through the point of maximum velocity.

3. The mean velocity in a vertical, within a maximum error of about 3 per cent. and an average error of 1 per cent., occurs at 0.6 depth.

4. The mean velocity in a vertical, within a maximum error of about 1 per cent. and an average error of zero, is given by the mean of the velocities at 0.2 depth and 0.8 depth.

5. The mean velocity in a vertical is from about 80 to 95 per cent. of the surface velocity, which percentage is slightly less for shallow streams than for deep streams.

The laws governing the distribution of velocities in open channels do not all hold for ice-covered streams. Fig. 67, reproduced from U. S. Geological Survey *Water Supply Paper* No. 337, is a typical example of a stream flowing under a complete covering of ice. The mean velocity does not occur at 0.6 depth for an ice-covered stream but it is given very accurately by the mean of the velocities at 0.2 depth and 0.8 depth.

Instruments for Measuring Velocity

The current meter is quite generally used for measuring velocities in open channels. This instrument consists of a suitable frame on which is mounted a wheel that is moved by the current and actuates a device for determining the number of revolutions in a given time. The rate at which the wheel revolves varies with the velocity of the current. Ordinarily the current meter is provided with a mechanism which completes an electric circuit at each revolution or at a given number of revolutions of the wheel, and wires from the meter properly connected to batteries and buzzer or other indicating device, enables the observer to determine the rate at which the wheel revolves. The so-called acoustic meter has a drum attachment which strikes after a given number of revolutions of the wheel, the sound being conveyed to the observer through a hollow tube, by which the meter is held. Other meters are arranged with mechanical recording devices. Current meters may be suspended from a cable or attached to a rod; the former are generally provided with electrical contact and are better suited to the gaging of large streams. Meters attached to rods are very convenient for gaging small streams.

Two general types of wheels are used on current meters: those having a vertical axis with cups attached to the outer perimeter, and those with a horizontal axis and blades of the screw-propeller shape. Each type of wheel has its advocates and probably each type is better suited to particular conditions.

The propeller-shaped wheels are believed to be more accurate for measuring turbulent water since they are not affected to the same extent by eddies and cross-currents, while the cup meters are affected equally by currents from any direction. It is probable, however, that any of the standard makes of current meters when properly used, under conditions to which they are suited, will give results accurate enough for ordinary stream-gaging work.

There are three different makes of current meters that have been extensively used in the United States—the Price meter, the Ott meter and the Haskell meter. Of these, the Price meter has cups attached to a wheel with a vertical axis, and the other two have wheels of the screw-propeller type which revolve on a horizontal axis.

The Price meter[1] has been adopted by the Water Resources Branch of the U. S. Geological Survey for its stream-gaging work and is more extensively used for this purpose than any other meter. Both electric and acoustic Price meters are manufactured.

The Ott meter[2] has recently been used in making turbine tests with satisfactory results.

The Haskell meter[3] has been used extensively by the U. S. Lake Survey for gaging the large rivers of the Great Lakes drainage system, and it appears to be particularly well adapted to this class of work.

Rating the Current Meter.—Before a current meter can be used, it is necessary to establish a relation between number of revolutions and velocity of water by moving the meter through still water at a known rate and determining the number of revolutions in a given time. This operation is called rating the meter. A meter may be rated from a boat moving at a uniform rate in still water but it is better to have this work done at a properly equipped rating station. A meter should be rated when new and at least once a year thereafter, and after any accident to the meter or alteration of parts that will be likely to change its rating.

The observations from a current meter rating give velocities in feet per second with corresponding revolutions per second.

[1] Manufactured and sold by W. & L. E. Gurley, Troy, N. Y.
[2] Sold in United States by Keuffel & Esser Co., New York.
[3] Manufactured by E. S. Ritchie & Sons, Brookline, Mass.

These values are usually plotted on ordinary cross-section paper, and the smooth line or lines passing through their mean position is called the *rating curve*. A rating curve for a small Price electric meter is shown in Fig. 68. Rating curves for all makes of current meters plot as straight lines and it is characteristic of such curves that there is a break in the line at a point usually corresponding to a velocity of from 4 to 6 feet per second.

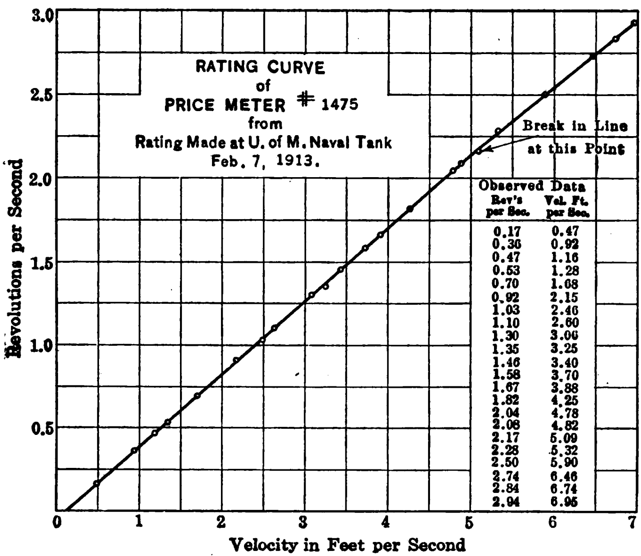


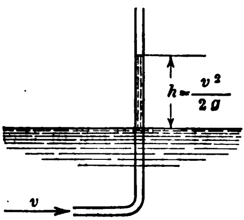
FIG. 68.—Typical rating curve for current meter.

From the rating curve a *rating table* is prepared, which gives velocities corresponding to different rates of revolution of the wheel. Table 86 is a rating table published by W. & L. E. Gurley. It is the mean of the ratings of ten small electric meters (Patterns Nos. 617 and 618) and is claimed by the makers to give values for any meter of similar pattern in good order, within an error of 1 per cent.

TABLE 86.—APPROXIMATE RATING TABLE FOR PRICE METERS NOS. 617, 618, 621, 623, AND 624, VELOCITIES IN FEET PER SECOND CORRESPONDING TO DIFFERENT TIMES AND NUMBERS OF REVOLUTIONS.

Time in sec.	Number of Revolutions												
	5	10	20	30	40	50	60	70	80	90	100	150	200
40	0.31	0.58	1.13	1.68	2.23	2.78	3.34	3.90	4.45	5.01	5.56	8.34	11.12
41	0.30	0.57	1.10	1.64	2.18	2.71	3.26	3.81	4.34	4.89	5.43	8.14	10.85
42	0.30	0.56	1.07	1.60	2.13	2.65	3.18	3.72	4.24	4.77	5.30	7.95	10.59
43	0.29	0.54	1.05	1.56	2.08	2.59	3.11	3.63	4.14	4.66	5.18	7.77	10.34
44	0.28	0.53	1.03	1.53	2.03	2.53	3.04	3.55	4.04	4.55	5.06	7.59	10.10
45	0.28	0.52	1.01	1.50	1.99	2.48	2.97	3.47	3.95	4.45	4.95	7.42	9.87
46	0.28	0.51	0.99	1.47	1.95	2.43	2.90	3.39	3.87	4.35	4.84	7.26	9.65
47	0.27	0.50	0.97	1.44	1.91	2.38	2.84	3.32	3.79	4.26	4.74	7.11	9.45
48	0.26	0.49	0.95	1.41	1.87	2.33	2.78	3.25	3.71	4.17	4.64	6.96	9.25
49	0.26	0.48	0.93	1.38	1.83	2.28	2.72	3.18	3.63	4.09	4.54	6.81	9.06
50	0.26	0.47	0.91	1.35	1.79	2.23	2.67	3.12	3.56	4.01	4.45	6.67	8.89
51	0.25	0.46	0.90	1.32	1.75	2.19	2.62	3.06	3.49	3.93	4.36	6.54	8.72
52	0.25	0.46	0.88	1.29	1.72	2.15	2.57	3.00	3.42	3.85	4.28	6.42	8.56
53	0.24	0.45	0.86	1.27	1.69	2.11	2.52	2.94	3.36	3.78	4.20	6.30	8.40
54	0.24	0.44	0.85	1.25	1.66	2.07	2.47	2.88	3.30	3.71	4.12	6.18	8.24
55	0.24	0.43	0.83	1.23	1.63	2.03	2.43	2.83	3.24	3.64	4.05	6.07	8.09
56	0.23	0.43	0.82	1.21	1.60	1.99	2.39	2.78	3.18	3.58	3.98	5.96	7.95
57	0.23	0.42	0.80	1.19	1.57	1.96	2.35	2.73	3.12	3.52	3.91	5.86	7.81
58	0.22	0.41	0.79	1.17	1.54	1.93	2.31	2.68	3.07	3.46	3.84	5.76	7.68
59	0.22	0.41	0.78	1.15	1.51	1.90	2.27	2.63	3.02	3.40	3.77	5.66	7.55
60	0.22	0.40	0.77	1.13	1.48	1.87	2.23	2.59	2.97	3.34	3.71	5.56	7.42
61	0.22	0.39	0.75	1.11	1.46	1.84	2.19	2.55	2.92	3.29	3.65	5.47	7.30
62	0.21	0.39	0.74	1.09	1.44	1.81	2.16	2.51	2.87	3.24	3.59	5.38	7.18
63	0.21	0.38	0.73	1.07	1.42	1.78	2.13	2.47	2.82	3.19	3.53	5.30	7.07
64	0.21	0.38	0.72	1.05	1.40	1.75	2.10	2.43	2.77	3.14	3.48	5.22	6.96

Pitot tubes are especially adapted to the measurement of velocities in pipes, and may be used for measuring velocities, in pipes and open channels, that are too high to be conveniently measured with current meters. In its simplest form the Pitot tube is a pipe bent to a right angle as shown in Fig. 69. When the shorter leg is pointed against the current, the water will rise a distance equal to the velocity head or $h = \frac{v^2}{2g}$. It has been shown by experiment that this relation holds rigidly. There are practical difficulties in the way of using the Pitot tube in its simplest form, since the distance which the water in the



Pitot Tube
FIG. 69.

tube rises above the water surface cannot be accurately determined.

To obviate this difficulty a second pipe, or static leg, is introduced, Fig. 70, the two pipes being clamped together and attached at the upper end to an air pump or provided with other means for exhausting the air. The static leg may be simply a straight pipe extending into the water or it may be bent at right angles and pointed downstream or otherwise arranged to measure the static pressure of the water. When this instrument is placed in running water, the air may be exhausted an equal amount in each leg and the water drawn up to an elevation convenient to read. The upper ends of the pipes should be of glass so that the height of water columns may be observed. There is always a certain amount of suction in the static leg so that the difference in height of water columns will not equal the velocity head. It will, however, be proportional to the velocity head.

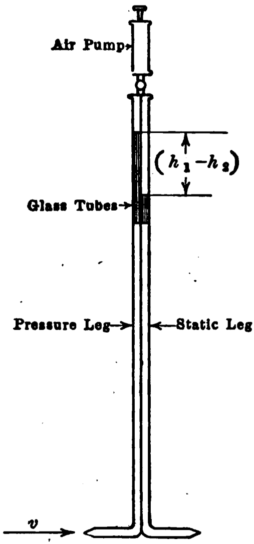


Fig. 70.

If $h_1 - h_2$ equals the difference in height of water columns, v the velocity of water being measured and c a coefficient that is constant for each instrument, the velocity is given by the formula

$$v = c\sqrt{2g(h_1 - h_2)} \tag{1}$$

To obtain c the instrument should be rated by moving it through still-water at a known velocity the same as for a current meter.

Floats are sometimes used for the approximate measurement of velocities in open channels. These may be classified as surface floats, subsurface floats and rod floats. The principal involved is the determination of the time required for a floating object to pass from one cross-section of a channel to another, the velocity of the float being considered the same as the velocity of the filaments of the water through which it travels.

A surface float may be any object floating near the surface and to sufficient depth to partake of the motion of the upper filaments. The mean velocity in the vertical will vary from about 80 per cent. of the observed surface velocity for the shallowest streams to 95 per cent. for very deep streams. Surface floats should not be used when there is sufficient wind to affect their movement.

A subsurface float consists of a small surface float connected by a fine line to a larger float, which is weighted to remain submerged and keep the line taut without drawing down the surface float. The submerged float being large, the effect of the surface float is usually neglected. To get the mean velocity in the vertical directly from this combination the submerged float should be submerged to about 0.6 of the mean depth of the stream along the path followed by the float. This float has little value for stream-gaging purposes. It is sometimes used for determining the velocity and direction of subsurface currents in lakes, harbors, and other large bodies of water.

Rod floats are made from wooden poles or hollow tin cylinders weighted at one end so as to cause them to float in an upright position with the unweighted end above the water surface. They should be submerged as much as possible without coming in contact with the bottom of the channel. Rod floats are usually assumed to give directly the mean velocity in the vertical. They are used more satisfactorily in artificial channels, or natural streams of regular section.

As the result of an extensive experimental investigation in which the flow in a wooden flume, determined from rod float measurements, was compared with the discharge over a sharp crested weir, Francis[1] deduced the following relation between the mean velocity in the vertical section along the path of a rod float and the velocity of the float:

$$v = v_r(1.012 - 0.116\sqrt{d'/d})$$

in which v is the mean velocity in the vertical, v_r is the mean velocity of the rod float, d is the depth of water, and d' is the distance from the bottom of the float to the bed of the channel. The above relation probably applies more accurately for small values of d'/d and should not be used where d' is greater than $0.25d$.

[1] J. B. Francis: Lowell Hydraulic Experiments, p. 195.

Discharge Measurements by Current Meter

Current-meter measurements may be made from a bridge, a car suspended from a cableway, or a boat, or if the stream is small enough the gaging may be made by wading.

The first step is to assume a permanent initial reference point and mark off distances, usually 5 or 10 feet, along the bridge or cableway or a special line stretched across the channel. For small streams, where the gaging is made by wading, a cloth tape is sometimes stretched across the stream from the initial point. Soundings are then taken and current-meter measurements are made to determine the depths and mean velocities in vertical lines at different points along the cross-section of the channel. Points of measurement are so chosen that the mean of the velocities in two adjacent vertical lines will give approximately the mean velocity of the portion of the cross-section of the channel between them. The mean velocity in a vertical (see pages 232 to 235) may be obtained by one of the following methods:

1. By plotting vertical velocity curves.
2. By taking the velocity at 0.6 depth.
3. By the mean of velocities at 0.2 and 0.8 depth.
4. By integration; that is, moving the meter slowly and at a uniform rate from the surface of the water to the bottom of the channel and back again, noting the time and number of revolutions of the meter. This method is not recommended for inexperienced observers.
5. By taking a velocity near the surface of the stream and applying a corrective factor (from 0.80 to 0.95) to reduce to mean velocity. This approximate method must sometimes be resorted to when the current is so swift as to make measurements at the depths required by any of the above methods impracticable.

If d_1 and d_2 represent the depths of water at two adjacent verticals where velocities have been observed, v_1 and v_2 the respective mean velocities and l the distance between the verticals, the discharge of the portion of the cross-section of the channel between the verticals is

$$l\left(\frac{v_1+v_2}{2}\right)\left(\frac{d_1+d_2}{2}\right) \qquad (2)$$

and the total discharge of the stream is the sum of such terms for the entire cross-section of the stream.

Points of measurement along the cross-section of the channel should be selected at abrupt changes in velocity or the profile of the bottom. Where conditions are fairly uniform it is customary to make measurements at equal distances apart. It is usually necessary to take one or two measurements close to both edges of the channel.

CURRENT METER NOTES

Date Apr. 15, 1916 Time 10 A.M. to 11 A.M. Stream Huron River
Observer C.O. Wisler Location Fuller St. Bridge, Ann Arbor, Mich.
Meter Price #12 Gage height, beg. 2.75 end 2.76 mean 2.76
Total area 295.9 Mean velocity 3.46 Dicharge 1023.5

OBSERVATIONS					COMPUTATIONS						
					VELOCITY						
Dist. from initial point	Depth	Depth of observat.	Time in seconds	Revolutions	At point	Mean in vertical	Mean in section	Mean depth	Width	Area	Discharge
0+3.5	0.35					0.79	0.79	.52	1.5	.78	0.6
+5.0	0.68	0.41	44.8	15	.6 Depth	0.79	1.37	1.29	5	6.45	8.8
+10.0	1.90	0.38	42.4	40	2.18	1.95					
		1.52	54.2	40	1.71		2.51	2.67	10	26.7	66.7
+20.0	3.44	0.69	54.4	90	3.80	3.07					
		2.72	54.4	60	2.34		3.29	3.72	10	37.2	122.2
+30.0	3.99	0.80	51.2	90	4.03	3.51					
		3.19	54.0	70	2.99		3.67	3.86	10	38.6	141.6
+40.0	3.73	0.75	49.6	90	4.18	3.82					
		2.98	53.2	80	3.46		3.74	3.74	5	18.7	70.0
+45.0	3.74	0.75	48.0	90	4.30	3.65					
		2.99	54.2	70	2.99		3.77	3.20	5	16.0	60.4
+77.0	2.19	0.43	51.4	90	4.03	3.53					
		1.70	53.2	70	3.03		3.56	1.57	2	3.14	11.2
1+1.0	1.00	0.60	51.2	80	3.59	3.59					
							3.42	1.38	2	2.76	9.4
1+3.0	1.75	0.35	50.0	80	3.67	3.25					
		1.40	57.2	70	2.82		2.65	1.15	5	5.75	15.2
1+8.0	1.55	0.31	51.4	60	2.70	2.06					
		1.24	49.4	30	1.41						
							Totals			295.9	1023.5

No 2 of 2 Sheets, Comp. by E.K.M. Chk. by C.T.M. Make notes on back.

On page 242 is shown a typical sheet of current-meter notes where the mean velocities in the verticals are obtained by the 0.2, 0.8 depth method. Methods of observation and computations may be seen from these notes.

A method similar to the above is followed in measuring the discharge of ice-covered streams. Holes must be cut in the ice to admit the current meter and in addition to measuring the depth of water the depth to the bottom of the ice must be determined, the latter being subtracted from the former to obtain the depth of water to be used in computing the area of cross-section.

The mean velocities in the verticals for ice-covered streams may be obtained:

1. By plotting vertical velocity curves, or
2. By obtaining the means of velocities at 0.2 and 0.8 depth.

Discharge Measurements by Pitot Tubes

In measuring discharges of open channels with Pitot tubes (page 238) the observations and computations will be similar to those described above for current-meter measurements. Pitot tubes are sometimes used for measuring velocities in pipes, in which case the following method of determining discharges may be used.

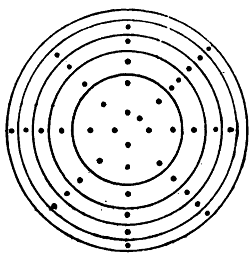


Fig. 71.

Velocities should be taken at a number of points in a cross-section of the pipe and these points should be plotted in their proper position in a circle, drawn to suitable scale, which represents a section of the water flowing through the pipe. Such a section is illustrated in Fig. 71. Velocities (not shown in figure) should be written adjacent to each plotted point. A convenient number of concentric circles, preferably 5 or 10, should be so drawn that rings of equal area will be formed. If d equals the diameter of the pipe the proper radii for the concentric circles for 10 rings will be, $0.16d$, $0.22d$, $0.27d$, $0.31d$, $0.35d$, $0.39d$, $0.42d$, $0.45d$ and $0.48d$. For 5 rings use alternate values beginning with $0.22d$. The mean velocity in each ring may then be obtained by observation, and the mean velocity for the pipe will be the average of the mean velocities for the rings.

Discharge Measurements by Floats

Before beginning a discharge determination by means of floats (page 239) it is necessary to select a uniform reach of channel and lay out two cross-sections of the stream from, say, 100 to 300 feet apart which will mark the places of beginning and ending float observations.

Fig. 72 illustrates a graphical method described by Unwin[1] for taking observations and making computations. Two cross-sections are selected L distance apart. Lines marked with tags every 10 feet, or at some other convenient interval

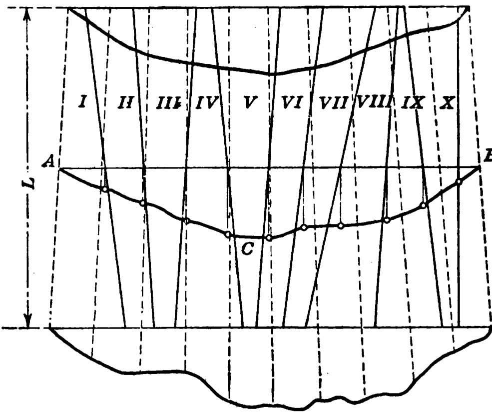


FIG. 72.

may be stretched across the stream over these sections. Soundings to get data for plotting the cross-sections are then made. As many float measurements as desired may be obtained, observers taking the time required for the floats to pass between the cross-sections and noting the place where the floats pass over each section.

From these observations a diagram similar to Fig. 72 may be prepared. The cross-sections are plotted to suitable scale and the channel is divided into equal sections by dotted lines. The paths of the floats are shown by full lines. The straight line AB is halfway between the water-surface lines of the two cross-sections. From the point where the full lines, representing the

[1] W. C. UNWIN: A Treatise on Hydraulics, p. 286.

paths of the floats, cut AB verticals are dropped on which the observed velocities for each float, corrected by the proper coefficient to reduce to mean velocity, are plotted to a convenient scale. The line ACB which connects the points thus obtained is the mean-velocity line. The mean velocities for Sections I, II, III, etc., are found by scaling the ordinates, in the middle of these sections, between lines AB and ACB. The discharge in any section is given by the product of the average end areas and mean velocities. The following table illustrates a method of keeping computations.

Section	End areas of section, square feet	Mean area of section, square feet	Mean velocity, feet per second	Discharge, cubic feet per second
I	27.2 30.7	28.95	0.41	11.9
II	41.1 45.1	43.1	0.98	42.2
III	66.6 67.2	66.9	1.37	91.6
IV	77.7 70.9	74.3	1.90	141.2
V	80.4 79.1	79.75	2.31	184.2
VI	85.5 79.7	82.6	2.20	181.7
VII	60.3 64.1	62.2	1.97	122.5
VIII	55.5 51.2	53.35	1.75	93.4
IX	50.2 46.2	48.2	1.37	66.0
X	35.5 31.0	33.25	0.45	15.0
Total......	....	....	....	949.7

Discharge Measurements by Traveling Screen

The traveling-screen method of measuring flowing water is adapted only to open channels of very regular cross-section.

This method requires quite elaborate preparations but when the apparatus is once installed it may be used for as many observations as desired.

A very light canvas screen, varnished to insure impermeability, is suspended by a stiff frame from a wheeled carriage mounted on tracks along the edges of the channel. The rate of movement of the screen must necessarily be the mean velocity of the water. A small crack, about 0.5 inch, should be provided between the screen and the sides and bottom of the channel to insure freedom of movement. The distance through which the screen moves is limited to the reach of uniform straight section. The velocity of the screen is usually determined electrically.

A similar method is sometimes employed in which the screen is suspended from floats, properly weighted to provide the right clearance between the screen and the bottom of the channel.

Theoretically a correction should be applied to provide for leakage around the screen. The error introduced by neglecting this correction is, however, very small. The area of the water cross-section should be carefully taken. The discharge will be the product of this area and the velocity of the screen.

Discharge Measurements by Color Method

This method has been employed for measuring the velocity in pipes. The process consists of injecting a solution of coloring matter, commonly fluorescein, into the pipe and observing the time required for it to move through a known distance. The particles of coloring matter will usually remain within a prism having a length equal to 1 per cent. of the distance traveled. The explanation of this phenomenon lies in the fact that in turbulent water there is a continual crosswise as well as longitudinal movement of the particles. This indicates that in general all particles of water are moving through the pipe with the same longitudinal velocity.

The coloring matter may be introduced at the intake of the pipe or it can be injected by a force pump or gun[1] into the pipe at any point. The second point of observation which must be at the outlet of the pipe should be at a distance at least 200 times the mean velocity in feet per second from the place where

[1] A gun for injecting coloring matter into pipes is described in U. S. Department of Agriculture *Bulletin* No. 376 by Fred C. Scobey.

the coloring matter is introduced. Time observations should be made at the instant the coloring matter is introduced and at the first and last appearance of the coloring matter at the second point of observation. The mean velocity will be the distance between the two points of observation divided by the mean of these two time intervals. The discharge of the pipe is the product of this mean velocity and the area of the pipe. This method is limited to conditions where the outlet of the pipe is exposed in order that the coloring matter may be seen.

This method could be modified by substituting for the coloring matter a concentrated salt brine or some other chemical that is a good conductor of electricity. Then two poles of an electric circuit, properly connected to batteries and a galvanometer, could be inserted in the water at the second point of observation. The galvanometer should show a stronger current while the prism containing the chemical is passing the poles. This method has an advantage in that it does not necessitate seeing the water. The second point of observation can be at any part of the pipe line, as it will only be necessary to drill small holes in the pipe to insert the poles.

These methods have never been applied to open channels but they would probably be satisfactory for fairly high velocities in smooth channels.

Discharge Measurements by Venturi Meter

There are a number of types of small service meters for measuring water for domestic purposes which automatically record the flow of water. These meters are adaptable only to conditions involving the measurement of flow through very small pipes. For measuring the flow through large pipes the Venturi meter has been quite generally adopted, and the principal which it involves may be applied under various conditions.

The principle of the Venturi meter was first stated in 1797 by J. B. Venturi an Italian, and was first applied by Herschel[1] to the measurement of flow in pipes in 1887. Fig. 73 shows a Venturi meter in horizontal position, with approximate dimensions as generally constructed. It resembles the frustrums of two cones having altitudes in the ratio of 1 to 3, with the top

[1] *Trans.* Amer. Soc. Civ. Eng., vol. 17, p. 228.

and bottom bases equal. The smaller bases are connected and form what is called the throat of the meter while the larger bases connect to the pipe. The direction of flow through the meter is from the shorter to the longer section. Two piezometer tubes are shown in the figure at the throat and entrance to the meter.

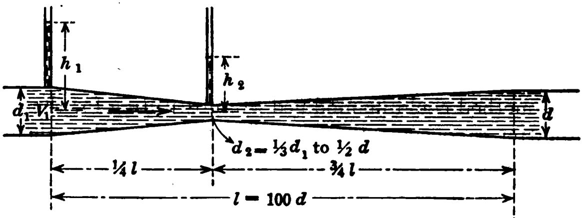


FIG. 73.—Venturi meter.

Let h_1 and h_2 represent the height above the axis of the meter to which the water rises in the piezometer tubes at the entrance and throat of the meter respectively, and let v_1, d_1 and a_1 and v_2, d_2 and a_2 be the corresponding velocities, diameters, and areas at the two places. Then from Bernoulli's theorem, neglecting friction

$$\frac{v_2^2 - v_1^2}{2g} = h_1 - h_2 \tag{3}$$

and since

$$Q = a_1v_1 = a_2v_2$$

the formula for discharge through a Venturi meter including the empirical coefficient c, becomes

$$Q = \frac{ca_1a_2}{\sqrt{a_1^2 - a_2^2}}\sqrt{2g(h_1 - h_2)} \tag{4}$$

or expressed in terms of diameter

$$Q = \frac{c\pi d_1^2d_2^2}{4\sqrt{d_1^4 - d_2^4}}\sqrt{2g(h_1 - h_2)} \tag{5}$$

For meters having a definite ratio of inlet to throat diameter

$$R = \frac{d_1}{d_2} \tag{6}$$

and putting

$$K = \frac{\pi R^2}{4}\sqrt{\frac{2g}{R^4 - 1}} \tag{7}$$

formula (5) may be written

$$Q = cKd_2^2\sqrt{h_1 - h_2} \tag{8}$$

The following table gives values of R with corresponding values of K.

R	2	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3.0
K	6.50	6.47	6.44	6.41	6.40	6.38	6.37	6.36	6.35	6.34	6.34

The value of c will depend upon the roughness of the interior surface of the meter. For clean cast iron the value of c will usually range from 0.97 to 0.99.

Venturi meters are manufactured[1] for permanent installations with the piezometer tubes connected to an automatic recording instrument which registers on a "Chart Recorder Dial" a continuous graphic record of the rate of flow through the meter. A "Register Counter Dial" shows the total volume of flow through the meter in cubic feet, gallons, or pounds and an "Indicator Dial" shows the present rate of flow.

Discharge Measurements by Chemical Gaging[2]

Chemi-hydrometry or chemical gaging consists of determining discharges by introducing a chemical at a known rate into flowing water, and determining the quantity of the chemical in the stream at a section far enough downstream to insure a thorough mixture of the chemical with the water to be measured. Common salt (NaCl) is the chemical usually employed, and chemical gaging is frequently referred to as the *salt-solution method.* For convenience the salt is dissolved in water to form a brine before being introduced into the stream.

Let Q represent the discharge of the stream in second-feet. If w pounds per second of salt are introduced, and after thorough mixture a sample taken from the stream shows that 1 pound of water contains n pounds of salt, then

$$\frac{w}{62.4Q} = \frac{n}{1} \text{ or } Q = \frac{w}{62.4n} \qquad (9)$$

The above formula is not readily applicable, owing to the fact that several factors enter into the determination of n which complicate the problem. The waters of natural streams usually

[1] Manufactured by the Builders Iron Foundry, Providence, R. I.

[2] For a full discussion of this subject see B. F. Groat: Chemi-Hydrometry and Precise Turbine Testing. *Trans.* Amer. Soc. Civ. Eng., vol. 80, p. 951.

Also F. A. Nagler: Verification of Bazin Weir Formula by Hydro-Chemical Gaging. *Proc.* Amer. Soc. Civ. Eng., Jan., 1918.

contain an initial quantity of salt in solution, which must be considered in making a correct gaging.

The method of "Special Dilutions" and "Balanced Evaporations" will be described. In this method a special dilution of the salt-solution sample, with the natural water of the stream is prepared. This special dilution should contain, as nearly as can be determined, the same quantity of salt per unit volume as the sample taken from the channel after salt has been introduced.

There are three sets of samples to be examined as follows:

1. The dosed stream water; that is, the water of the stream after salt has been introduced and the salt has become thoroughly mixed with the water of the stream.

2. The salt-solution sample; that is, the brine which is prepared to be introduced into the stream.

3. The special dilution; that is, the mixture of the salt solution with the natural stream water, prepared in the laboratory.

By this method it is not necessary to analyze the natural stream water, as the effect of the salt which it contains is eliminated in the computations.

A saturated solution of salt and water contains about 20 pounds of salt per cubic foot of water. It is usually desirable to have the brine which is to be introduced into the water as concentrated as possible in order to reduce the size of the mixing tank. A saturated solution is inadvisable owing to the tendency of the salt to crystallize at the edge of the tank, but a solution consisting of 16 pounds of salt per cubic foot of water will be satisfactory.

Salt solution should be added to the stream at such a rate as to increase its salt content by at least 0.003 pounds per cubic foot and under no circumstances should the initial salt content exceed 25 per cent. of the salt content of the dosed water. For example, a stream having an approximate discharge of 100 second-feet should have salt added at the rate of at least 0.3 pounds per second and if the natural stream water contained say 0.0009 pounds of salt per cubic foot the salt should be added at a minimum rate of 0.36 pounds per second.

For obtaining the maximum accuracy in making chemical tests the method of balanced evaporation should be used. This requires that the dosed stream water and the special dilution samples be evaporated and that the salt-solution sample be diluted until each contains, as nearly as can be estimated, the

same quantity of salt in the sample analyzed. From the dosed stream water and for the special dilution, samples of 500 cubic centimeters may conveniently be selected. These should then be evaporated until the volume is about 10 cubic centimeters. A 10-cubic centimeter sample of the salt solution which contains approximately the same amount of salt as these samples should then be obtained by dilution.

Preparing Special Dilutions.—Special dilutions should be prepared with great care. Assuming that a dilution of 1 in 2500 is desired it may be obtained in the following manner. The contents of two 10-cubic centimeter pipettes are discharged into a 500-cubic centimeter volumetric flask which has been previously washed with some of the natural stream water sample. The flask is then filled to the 500-cubic centimeter mark from the natural stream water sample, and inverted about 40 times to insure a thorough mixture, the temperature of the salt solution and natural stream water being recorded. This solution then has a ratio of dilution of 25 to 1. The volume of one 10-cubic centimeter pipette filled with this "stock" solution is then discharged into a 1000-cubic centimeter volumetric flask which has been previously washed with some of the natural stream water sample. The flask is then filled with natural stream water up to the 1000-cubic centimeter mark and thoroughly shaken to insure a good mixture of the two solutions, the temperature of each solution being recorded. The resulting mixture then has a ratio of dilution of 1 in 2500.

Dilutions of the salt solution sample with distilled water are made in a similar manner. If the special dilution is to be evaporated to one-fiftieth of its original volume, the ratio of dilution, being, say, 1 in 2500, the salt solution sample which is not evaporated should be diluted in the ratio of 50 to 2500 or 1 to 50.

Evaporation of Samples.—The samples may be conveniently evaporated in the following manner. A sample of say 500 cubic centimeters is first measured in a volumetric flask, the temperature being noted. This is then emptied into a separatory funnel, arranged to discharge into a casserole of about 100-cubic centimeters capacity which is heated by means of a gas jet under a water bath or by an electric heater. Small quantities of the sample are dropped into the casserole at intervals as required. The sample should be evaporated at a temperature slightly below the boiling point. An electric fan blowing over the sur-

face of the water will hasten evaporation. From 5 to 10 hours will be required to evaporate a 500-cubic centimeter sample, depending upon the humidity of the air and the success in producing artificial air currents. After the sample has entirely run out the separatory funnel should be washed with distilled water, which should also be evaporated. The evaporation should continue until about 10 cubic centimeters remain in the casserole.

Samples of both the dosed stream water and special dilutions are evaporated in this manner. The contents of a 10-cubic centimeter pipette of the dilutions of the salt-solution sample are emptied directly into a casserole. The three samples are now ready for the chemical test or titration.

Titrating Samples.—The reagent used in the salt analysis is silver nitrate, which is dissolved in distilled water in some standard proportions. It is essential that a sufficient quantity of this solution be prepared at one time, to make all of the tests required for one discharge measurement. The silver nitrate solution should be kept in a dark-colored bottle and be placed in a dark closet to prevent action by light. The strength of solution for conducting the test should not be less than about 1.5 grams of *chemically pure* silver nitrate to 1 liter of distilled water.

A potassium bichromate solution having a concentration of 50 grams per liter may be used to indicate the end point in the reactions of the silver nitrate upon the sodium chloride. About 6 or 7 drops of this solution will be sufficient for samples of the strength of those described above.

The titration of the above samples requires about 50 cubic centimeters of the silver nitrate solution. A 100-cubic centimeter burette containing more of the silver nitrate solution than will be required for a test is placed above the casserole containing the sample to be analyzed, and an initial reading of the burette is taken. One drop of potassium bichromate is added to the initial sample and silver nitrate solution is admitted from the burette at the rate of about 4 drops per second until the end of the reaction is nearly reached. The sample should be stirred continuously with a glass rod and 1 drop of potassium bichromate should be added for each 10 cubic centimeters of the silver nitrate solution. As the end of the reaction approaches, the rate of admitting silver nitrate should be reduced to about 1 drop in 2 seconds. The potassium bichromate gives the sample a yel-

low color, which is replaced by a permanent orange tinge when the end of the reaction is reached. This means that the point has been reached where the silver nitrate admitted has just neutralized all of the salt in the sample. A final reading of the burette should be made at this point. The amount of silver nitrate used is a measure of the quantity of salt contained in the sample. Some difficulty may be experienced at first in detecting the end of the reaction as the change in color is not very marked, but with a little experience this point may be determined with considerable accuracy. It is important that about the same amount of silver nitrate and the same amount of potassium bichromate should be used in making all of the tests for a single discharge measurement.

The following is a list of the principal laboratory apparatus

1 balance with weights, sensitive to 1 milligram.
1 rough scales for weighing salt.
1 four-unit evaporator.
4 ½-liter separatory funnels.
1 100-cubic centimeter burette.
8 number 3 casseroles.
1 1-liter volumetric flask.
1 500-cubic centimeter volumetric flask.
1 100-cubic centimeter volumetric flask.
1 thermometer.
2 10-cubic centimeter pipettes.
3 1-liter flasks.
25 1-gallon bottles for samples.
5 1-quart bottles.

The quantities of salt, silver nitrate and potassium bichromate that will be necessary will depend upon the flow of the stream, and the number of measurements to be made. A bottle of hydrochloric acid should be kept on hand for cleaning casseroles, but care should be taken to wash away all traces of the acid from the casseroles before using them for a new test.

Determination of Discharge.—The following nomenclature is used:

Q = Discharge of the stream in second-feet.
q = Discharge of salt solution in second-feet.
r' = Ratio of volume of natural stream water to volume of salt solution in the special dilution.

R' = Ratio of volume of total mixture to volume of salt solution in the special dilution.

t = Volume of silver nitrate solution required to titrate a unit volume of the salt-solution sample. In other words if the unit volume is 1 liter, t = the difference between initial and final readings of the burette for the silver nitrate solution multiplied by the ratio of dilution of the salt-solution sample multiplied by 1000 and divided by the volume in cubic centimeters of the sample discharged into the casserole.

t_2 = Volume of silver nitrate solution required to titrate a unit volume of the dosed stream sample. Or, for unit of 1 liter, t = difference between initial and final readings of burette multiplied by 1000 and divided by the actual volume in cubic centimeters discharged into the separatory funnel for evaporation.

t'_2 = Volume of silver nitrate solution required to titrate a unit volume of the special dilution. Or, similar to t_2, t'_2 = difference of burette readings multiplied by 1000 and divided by the actual volume in cubic centimeters discharged into the separatory funnel for evaporation.

The discharge of the stream is given by the following equation:

$$Q = q \frac{r'}{1 + R' \dfrac{t_2 - t'_2}{t - t_2}} \tag{10}$$

The above formula is accurate enough for ordinary work. Where great refinement is desired a shrinkage coefficient may be applied to correct for shrinkage of volume caused by mixing two salt solutions of different densities. Such corrections, however, will not ordinarily effect the final discharge more than a small fraction of 1 per cent. All flasks, pipettes, etc., used for measuring volumes should be calibrated with great care at different temperatures. Where great precision is required all volumetric measurements should be corrected for temperature by reducing all volumes to volumes at some particular temperature. Ordinarily, however, if care is taken to make all measurements at as nearly a uniform temperature as possible such corrections will not be necessary. If the variation in temperature during a test is not more than 20°F. the error introduced into the results by neglecting temperature corrections will not be

more than 0.5 per cent. A detailed discussion of the sources of error in the measurement of water by the method of chemi-hydrometry and the derivation of formula (10), together with correction factors to be applied for the more precise application of the method is given in Mr. Groat's valuable paper.[1]

Operations for Obtaining Samples.—Various methods of introducing the salt solution and taking samples have been suggested. The one described below will be satisfactory for open channels. While the salt solution is being introduced samples should be taken as follows:

(*a*) Sample of salt solution.
(*b*) Sample of natural stream water.
(*c*) Sample of dosed stream water after the salt solution has become thoroughly mixed with the water in the stream.

Before beginning the measurement an apparatus for introducing the salt solution at a uniform rate must be provided. This may consist of a mixing tank and a discharge tank, preferably arranged at such elevations that the former may discharge into the latter by gravity. A satisfactory arrangement is shown in Fig. 74. The mixing tank *ABCD* should be large enough to contain solution for the entire measurement after the discharge tank *EFGH* has been filled from it. The area of a horizontal section of the discharge tank need not be more than 1 or 2 square feet, and the height of the tank should be at least 2 feet. A pipe *P* leads water from the discharge tank to the point where the solution is to be introduced into the stream.

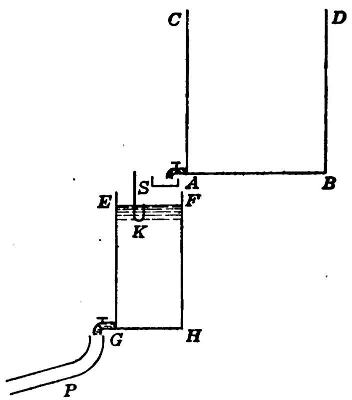


FIG. 74.

The salt for one test is placed in the mixing tank and the water added. All of the salt should be dissolved by stirring before any of the solution leaves the tank. After all the salt

[1] *Trans.* Amer. Soc. Civ. Eng., vol. 80, p. 951.

is dissolved the solution passes through the valve A and a 40-mesh screen S to the discharge tank. The elevation of the surface in the discharge tank is maintained at the elevation of the fixed hook K by hand regulation of the valve A. The valve G is set by trial, to the proper rate of discharge by noting the time required to fill a carefully calibrated vessel. The valve as thus set is left unchanged until the end of the measurement. For a depth of 2 feet in the discharge tank the elevation of the surface of the solution may vary 0.04 feet without affecting the discharge at G by more than 1 per cent. There should be no difficulty in regulating this elevation within 0.02 feet.

A continuous sample of the salt solution may be taken from a small perforation in the side of either tank. The sample of natural stream water should be taken above the point where the salt solution is introduced and during the period that it is being introduced. The dosed stream sample should be taken far enough downstream and after sufficient lapse of time from the time of beginning dosing, to insure a thorough mixture of the maximum quantity of salt that the stream should carry. These samples should preferably be continuous samples requiring some little time to secure. An air-tight can containing a small perforation to permit the entrance of water when the can is immersed and another perforation connected by a small pipe or tube to the air would be satisfactory for the purpose. Ordinarily dosed stream samples should be taken at more than one point in the cross-section of the stream in order to determine whether the mixture of the salt with the stream is satisfactory.

It will usually be necessary to make preliminary investigations to determine the proper place for taking samples of dosed stream water and the necessary time interval between the time of beginning dosing and taking the sample. Parker[1] gives the following approximate rules.

Let v represent the mean velocity of the stream and b its width. Then for streams with depths between $\frac{1}{10}b$ and $\frac{1}{8}b$ complete mixture does not occur until a distance of at least $6b$ has been traversed, and the discharge of the solution has continued for a period of at least $24\ b/v$ seconds.

It is apparent that the chemical method of gaging is more suitable to turbulent waters, and it is doubtful whether it can be applied satisfactorily to sluggish streams.

[1] Philip A. Morley Parker: Control of Water, p. 73.

Continuous Stream-discharge Records

In order to properly understand the fluctuations in flow and to estimate the available discharge of a stream continuous daily discharge records extending over a period of several years are essential. Frequently erroneous and misleading results will be obtained by basing conclusions on a few scattering discharge measurements or even on continuous records for 1 or 2 years.

The best data on which to base an estimate of the future discharge of a stream are records of discharge for preceding years, but such records to be a trustworthy guide should over a period long enough to include a wide range of conditions of flow. Usually records for a period of 10 years will give a good idea of normal conditions of flow but they should not be depended upon to give extreme low water or flood conditions.

Appreciating the importance of this matter, the U. S. Geological Survey in 1888 began a systematic gaging of the more important streams in the United States. As a result continuous discharge records of many streams for long periods of years have been kept, and on other streams, owing largely to inadequate appropriations, the records are more or less fragmentary and intermittent. All of the stream-discharge records of the U. S. Geological Survey are published in its Water Supply and Irrigation Papers.[1]

The general method of procedure to obtain data for continuous discharge records is indicated in the following outline:

1. Select a suitable location for a gaging station.
2. Install gage, build necessary structures and put station in permanent condition. Employ gage reader or otherwise provide for keeping a continuous record of stage.
3. Make discharge measurements at different stages of the stream through as wide a range in fluctuation as possible, keeping a record of gage height at the time each discharge measurement is made.
4. After sufficient discharge measurements have been obtained, prepare a discharge curve with discharges as abscissas and corresponding gage heights as ordinates.

[1] These papers may be obtained as published by applying to the Director of the U. S. Geological Survey or they may be purchased from the Superintendent of Documents, Washington, D. C. Most of the older issues are now out of print.

5. From the discharge curve prepare a table giving discharges corresponding to gage heights for each 0.01-foot interval.

6. From the discharge table and daily gage records prepare a table of daily discharges.

7. After the discharge curve has been completed discharge measurements should be made from time to time to check the curve. If these points indicate that the relation between gage height and discharge has changed, the curve should be corrected.

The above steps will be considered in detail in the following pages.

Selection of Site for Gaging Station.—The following discussion assumes that discharge measurements are to be made with a current meter. It applies, however, to other methods of measurement except as it refers to the actual determination of discharges. Below is given a list of the essential points to be considered in making a reconnaissance for determining the most suitable location for a gaging station.

1. General location of place at which records are desired.
2. Structure from which current-meter measurements are to be made.
3. Conditions favorable to a constant relation between gage height and discharge.
4. Uniform channel conditions at section where current-meter measurements are to be made.
5. Accessibility of site.
6. Availability of gage reader or attendant.
7. Cost of construction and maintenance.

Before definitely selecting a site for a gaging station it is sometimes necessary to determine the general locality that will give the best records of discharge for a given portion of the drainage area of a stream. In special cases a definite section of the stream may be given where discharge records are required, but frequently the engineer is allowed considerable discretion in the matter. Usually the discharge will not vary greatly between the points where two tributaries enter a stream, and in cases where a general investigation only is being made the exact locality where records are obtained is not essential.

Whenever practicable, it is customary to so locate the gaging station that current-meter measurements may be made from an existing bridge. If this is not feasible, a structure must usu-

ally be provided. For small streams a foot bridge may be constructed, and in streams not more than 3 feet deep current-meter measurements may be made by wading. Streams not over 800 feet wide are frequently spanned by a wire cable on which a car is operated by the observer. Current-meter measurements in large streams are sometimes made from boats anchored at various points along the cross-section, the position being obtained by transits on shore or by means of a sextant.

Probably the most important consideration in selecting the location for a gaging station is to chose a place for installing the gage, where the channel conditions are such that a constant relation between gage height and discharge may be maintained. This necessitates a good *control;* the control being that portion of the stream bed, usually below the gage, which controls the elevation of water surface at the gage. Streams are commonly made up of alternate reaches of slack water and ripples or rapids. The head of a rapids is necessarily of a more or less permanent character and usually it controls the elevation of the water surface for some distance upstream. The proper location for the gage is evidently in the slack water a short distance above the rapids. A similar condition may be obtained by a bar or large boulders which obstruct the flow of the stream and cause the water to back up behind them.

If the control is permanent the shifting of bars or other slight changes in channel conditions above it will have little or no effect on the elevation of water surface at the gage, but any change in the control will immediately effect this elevation. Sometimes the channel of a stream has such a permanent character that the stream bed itself provides a satisfactory control. On streams where a good natural control is not available an artificial control may be constructed. Such a control may be an obstruction, built of wood or concrete, usually in the form of a low weir extending across the channel. Some streams with shifting beds have no natural control and an artificial control cannot be maintained. In such cases there can be no permanent relation between gage height and discharge and special methods for obtaining discharge records are necessary (see page 273).

The river channel, at the place selected for making current-meter measurements, should be free from large rocks and other obstructions; there should be a straight reach of channel above and below the cross-section to be gaged; there should be no eddies nor slack water; and velocities should be measurable,

neither too high nor too low, for all ordinary stages of the river. As a matter of convenience the current-meter measurements should be made at a point close to the gage but this is not necessary, providing the gage is not so far away that the stream will change materially in stage during the time occupied by the observer in walking between the two places. Current-meter measurements during low stages of the stream are sometimes made by wading at some place more satisfactorily than the regular station.

A gaging station should be readily accessible from a railway station or highway. Since several discharge measurements must usually be made each year a location should be chosen which will entail the smallest expense possible for making trips.

If a non-recording gage is installed at a gaging station the daily attendance of a gage reader is necessary. A recording gage should ordinarily be visited once a week to change sheets or to see that the gage is operating properly. These matters should therefore be given careful consideration in selecting a site.

The cost of constructing and maintaining a gaging station should also be investigated. If records are wanted for a comparatively short time the first cost should be reduced as much as possible. On the other hand, if a permanent station is to be established the first cost may be comparatively unimportant. The relative accuracy of results to be obtained by the different types of installation should also be considered in this connection.

Installation and Description of Gages.—After selecting the site for a gaging station the gage should be installed and all work required to clean out and improve the channel should be completed as soon as practicable. A gage reader or attendant should then be employed and the taking of gage records should be begun without unnecessary delay.

Gages may be classified as recording and non-recording. The most common form of non-recording gage is the staff gage which may be erected in either a vertical or inclined position. A staff gage may be a strip of board or a thin sheet of metal attached to a board, which is graduated to tenths of a foot in elevation. Gages in 2 or 5 feet sections of sheet steel with enamelled faces and subdivisions, are accurate, convenient, and more durable than ordinary painted staff gages. In reading the gage hundredths of a foot should be estimated.

A vertical staff gage should be rigidly attached to a bridge

abutment, rock, or other permanent object in such a manner that there will be no danger of its becoming dislodged by ice, drift, or otherwise. It should be placed in quiet water and so faced that it may be easily read. The gage should extend deep enough into the water and be long enough to insure a reading for the lowest and highest stages of the stream.

Inclined staff gages should be made of 4 by 4-inch or heavier timber bolted to concrete supports. Marks should be placed with a level at 0.1 foot intervals of elevation. Inclined gages are not as trustworthy as vertical staff gages and should not be used when a suitable place for installing the latter can be found.

The elevation of water surface is sometimes obtained by suspending a plummet from the end of a tape or chain and measuring the distance to the water surface from some fixed point overhead as from a mark on a bridge or overhanging tree. This method may be resorted to when conditions are favorable and a satisfactory location for a staff gage cannot be found.

A gage should always be carefully referenced to two permanent bench marks, preferably located so that a comparison of some mark on the gage can be made with at least one of the bench marks from a single set up of the level. The gage should be checked from a bench mark at frequent intervals as the reliability of the records obtained depends upon the maintenance of the gage at an absolutely fixed elevation. In case the gage is accidentally moved or destroyed, it should be carefully replaced so as to give the same readings that it gave in its original position.

There are a number of different recording gages on the market which give a continuous record of stage. A common type of recording gage consists of drum which is revolved by a float as the stage changes and a pencil, actuated by a clock, which moves across the face of the drum parallel to its axis. A sheet of properly ruled cross-section paper is fastened to the drum and on this a graph is traced giving the height of water surface and corresponding time. Usually these gages are provided with an 8-day clock, and the sheet of paper is just large enough to last through this period. It is necessary therefore for an attendant to visit these gages once a week to replace the paper and wind the clock. A non-recording gage should always be erected close to a recording gage and the two gages should be adjusted to give the same reading. Whenever a new sheet of

paper is placed on the recording gage it should be set accurately as to time and gage reading as given by the non-recording gage and the date, time, and gage reading should be written on the sheet near the point where the record begins. When the sheet is removed the date and time and reading of the non-recording gage should be written near the point where the record ends. This provides for the adjustment of intervening records where such adjustment is necessary and insures against a possible error from using the wrong foot mark in taking records from the graph.[1]

There are two types of recording gages, operated by weight-driven clocks, which are designed to run from 2 to 3 months without attention. These are the Stevens[2] gage and the intermittent Gurley[3] gage. The Stevens gage gives a record in the form of a hydrograph similar to that described above but the method by which it is produced is reversed in that the clock revolves the drum and the float moves the pencil. The paper is fed from a large roll which contains about one year's supply. Records may be removed as desired, and if the gage is operating properly, it requires no attention oftener than is necessary to wind the clock.

The Gurley gage has three type wheels, one containing the time, which is operated by a clock and two which give the elevation of the water surface to feet and hundredths of a foot are controlled by a float. A record of the elevation of the water surface is printed every 15 minutes when a rubber-faced hammer strikes a strip of carbon backed paper which passes over the type wheels.

The Stevens gage and Gurley intermittent gage give satisfactory results when properly installed and they require less frequent attention than other gages. They are rather complicated, however, and considerable skill is necessary to properly install and operate them. If the expense of weekly attention is not too great, one of the simpler and less expensive gages will prove equally satisfactory.

Recording gages should be securely housed in order to protect them from storms and the possible ravages of lawless persons. Gage houses are usually built over wells connected to the stream

[1] Gages of this type are manufactured by Julian P. Friez, Baltimore, Md., and W. & L. E. Gurley, Troy, N. Y.

[2] Manufactured by Leupold & Voelpel, Portland, Ore.

[3] Manufactured by W. & L. E. Gurley, Troy, N. Y.

through a pipe, which should lie below the lowest water-surface elevation. At permanent stations the gage house and well should preferably be constructed of concrete. In cold climates the well should be banked up by earth to protect against freezing and in some cases artificial heat within the well must be provided. Specific directions for setting up, operating, and protecting the different makes of gages are given by the manufacturers.[1]

In deciding as to the advisability of installing a recording or non-recording gage several points must be considered. Those favorable to the installation of a non-recording gage are:

1. Cheaper first cost.
2. No mechanism to get out of order.

The recording gage possesses the following advantages:

1. Gives a continuous record.
2. Lower maintenance cost.
3. Does not require daily attendance, and therefore
4. May be installed in more remote places.
5. Reliability of record not subject to idiosyncrasies of gage reader.

On streams subject to a wide daily fluctuation in flow, due to artificial regulation by power plants or from other causes, a recording gage is essential. On streams having a fairly uniform flow, with a reliable gage reader, the records from a non-recording gage where readings are taken once or twice daily, may be entirely satisfactory.

Discharge Measurements.—Discharge measurements at a gaging station are usually made with a current meter, but other methods may sometimes be preferable. The different methods of measuring flowing water have already been described and of these the following are, under proper conditions, suitable for measuring discharges of natural streams:

1. Current meter (see pages 235 and 241)
2. Floats (see pages 239 and 244).
3. Weirs (see Chapters IV and V).
4. Chemical gaging (see page 249).

The current-meter method of determining discharges is satisfactory, provided the velocity is measurable and the flow

[1] For fuller discussion of this subject see JOHN C. HOYT and N. C. GROVER: River Discharge, pp. 23–36.

is not too turbulent. Ordinarily floats should not be used if a current-meter measurement is practicable. If, however, a current meter is not available or if it is required to measure a stream at flood stage where a meter cannot be operated, the float method may be necessary.

A weir, if properly constructed, provides the most satisfactory means of obtaining continuous discharge records. If a sharp-crested weir is used the discharge corresponding to a given head may be obtained directly from formula (7), page 72. If a weir has a cross-section similar to any of the sections given on pages 132 to 138, the coefficients corresponding to the particular shape of crest may be taken from Tables 42 to 53 inclusive, pages 143 to 148, and applied to formula (1), page 128. If a weir having a cross-section for which no experimental coefficients have been obtained is to be used, the discharges corresponding to different gage heights should be measured. If a weir is properly constructed, the control for the gaging station is permanent. There is usually, however, a tendency for silt to deposit back of the weir and increase the velocity of approach. This condition should be carefully studied and from time to time measurements should be made to check the relation of gage height to discharge. For permanent stations sharp-crested weirs will not usually be as satisfactory as weirs of some other type as it will be found difficult to maintain a sharp crest.

Streams can ordinarily be measured, with a current meter, at low and medium stages with little difficulty, but to complete the discharge curve measurements at flood stages are required. These are often difficult to obtain, partly because of the short duration of such stages and also because of rapid changes of stage, swift currents, and obstruction of the stream surface by floating drift or ice. Under such conditions accurate current meter measurements become impossible (see page 266). Very often flood discharges may more readily be obtained by using an adjacent dam as a weir, after selecting a suitable coefficient. It is desirable that a profile and section of the dam shall have been obtained previously during low water stages. In general, the dam becomes increasingly more accurate and the current meter less so as the stage increases.

The method of chemical gaging is well adapted to small turbulent streams where a straight uniform reach of channel, suitable for current-meter measurements, cannot be found. Such streams are frequently encountered in rocky, mountainous

districts, where the channels are rough but usually of a permanent character. There is, under such conditions, little difficulty in locating a gage above a permanent control, and a discharge curve once determined, may be used indefinitely. The comparatively high cost of measuring discharges may therefore be justified, if records for a long period are desired.

Discharge Curves.—A discharge curve may be obtained by plotting on ordinary cross-section paper, discharges as abscissas with corresponding gage heights as ordinates and drawing a smooth curve through the mean position of these points. If the gagings have been properly made the points should lie very close to the curve.

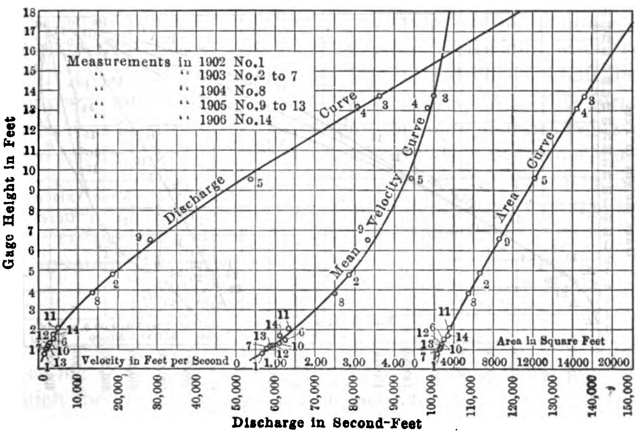


FIG. 75.—Discharge, mean velocity, and area curves.

An area curve is a graphical representation of the area of the cross-section of the channel for different gage heights. Data for the curve are obtained by taking areas, corresponding to proper intervals of gage height, from a plotted cross-section.

For each gaging of a stream a value of the mean velocity for the particular gage height may be obtained by dividing the discharge by the area. From the values thus obtained a mean-velocity curve may be plotted.

Fig. 75 shows typical discharge, mean-velocity and area curves. The same vertical coördinates are used for each curve. For corresponding gage heights the abscissa of the discharge

curve is evidently the product of the abscissas of the other two curves. Area and mean-velocity curves when plotted in connection with discharge curves may assist in determining the accuracy of individual measurements by showing whether a discrepancy is due to erroneous measurement of area or velocity.

During a rising stage the flow of a stream is greater, for a given gage height, and during a falling stage less than when the flow is uniform. It is therefore important that gage readings at the beginning and end of a discharge measurement should be as nearly equal as practicable. Fig. 76 is a discharge curve for a rising and falling flood, the points 5 to 17 inclusive indicating the sequence of measurements during the flood. The

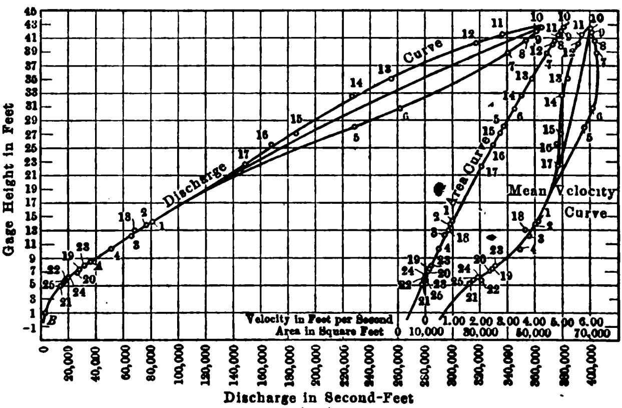


FIG. 76.—Typical discharge, curve for flood stages.

discharge curve for a rising flood is below and for a receding flood above the discharge curve for a constant stage, the amount of divergence increasing with the rate of change in stage.

Straight-line Methods of Plotting Discharge Curves.—It frequently happens that there are not sufficient measurements to determine a discharge curve accurately, when plotted by the method described above, or it may be desired to extend the curve above or below the range of plotted points. In some instances it may be necessary to plot the best curve possible from a very limited number of measurements or even from a single measurement. In such cases it is customary to select coördinates that are respectively functions of the gage height

and discharge, such that, when the values of these functions for given discharge measurements are plotted, they will lie on a straight line. Two methods of plotting discharge curves as straight lines will be described.

Logarithmic Discharge Curves.—From an investigation of many discharge curves it has been found that they may be approximately represented by an equation of the form

$$Q = p(G - e)^n \qquad (11)$$

Q being the discharge in second-feet, G the gage reading in feet and p, e and n constants. If e is given a value such that $G - e = 0$ when $Q = 0$, and the logarithms of Q and $G - e$ for given discharge measurements are plotted on ordinary cross-section paper, the points should lie very close to a straight line. If equation (11) held rigidly for all stages of a stream, e would be the gage height of zero discharge but for extremely small discharges, the actual curve departs somewhat from this form, as there is usually a small discharge for some distance below a gage reading of e. It will therefore be necessary to consider e as the value that must be used to make the corresponding logarithms of Q and $G - e$ plot on a straight line. It is slightly greater than the gage height of zero discharge.

Equation (11) may be written

$$\log Q = n \log (G - e) + \log p \qquad (12)$$

which is evidently the equation of a straight line referred to the axes log Q and log $(G - e)$, n being the tangent of the angle which the line makes with the log $(G - e)$ axis and p the intercept on the Q axis. After the line has been plotted the equation of the curve may be obtained by taking n and p from the diagram, and substituting their values in equation (12) which in turn may be transformed to the form of equation (11).

Fig. 77 shows a logarithmic and ordinary discharge curve (that is a discharge curve plotted on ordinary cross-section paper with gage heights and discharges for coördinates) of the Huron River at Fuller St. Bridge, Ann Arbor, Mich. A method of obtaining e graphically is also indicated. The ordinary discharge curve is first plotted as accurately as possible, and on this curve the points A, B, and C are so selected that the discharges to which they correspond are in geometric progression. In this case 200, 800, and 3200 second-feet were chosen though any other points in geometric progression such as 500, 1000, and

2000 second-feet might have been used. The main considerations are to select three points where the curve is accurately established and if possible to choose a ratio which will locate two of the points near the lower end and one quite well up on the curve. From the points A and B vertical lines are extended upward and from the points B and C horizontal lines are drawn which intersect the vertical lines at E and D. The lines DE and BA are then drawn to their intersection F, and the vertical

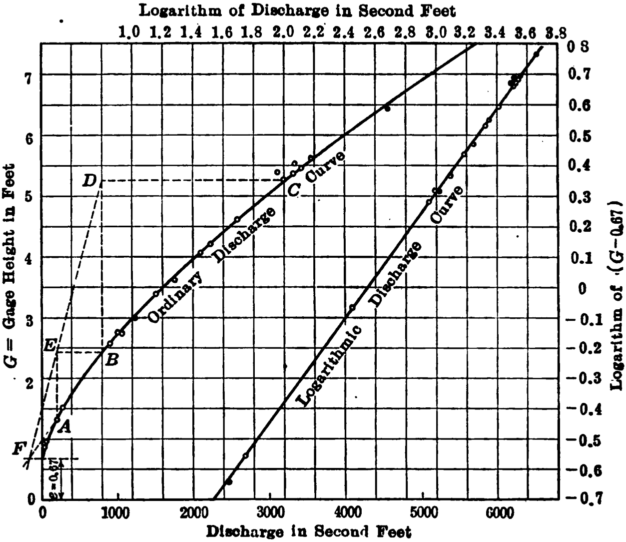


FIG. 77.—Logarithm discharge curve.

distance of F from the origin is e, the quantity sought. This method is theoretically correct[1] but may give a result slightly in error due to inaccuracy in plotting.

After e has been determined values of Q and $G - e$ may be plotted on logarithmic paper or the logarithms of these quantities may be plotted on ordinary cross-section paper. The points should lie close to a straight line but a difference of a few hundredths in e will greatly affect the positions of points for the smaller discharges and it may be that on first trial the lower

[1] For the proof of this method see THEODORE R. RUNNING: Empirical Formulas, p. 47.

points will not fall exactly in line with the upper ones. A slight correction to the value of e will then be necessary. The logarithm of the required correction will be given approximately by the vertical distance from the lowest plotted point to a straight line passed through the upper points.

After the logarithmic discharge curve has been satisfactorily plotted the equation of the curve may be written or any desired point may be transferred directly to the ordinary discharge curve. The equation of the curve shown in Fig. 77 is

$$Q = 351(G - 0.67)^{1.451} \tag{11a}$$

The ordinary discharge curve as plotted is a graph of this equation. It is evident that in this case a logarithmic discharge curve could have been drawn with practically the same result from a much smaller number of points.

Theoretically three measurements at different stages of a stream will determine the equation of the discharge curve. The three corresponding values of Q and G can be substituted in equation (11) and three simultaneous equations from which p, e and n may be determined will result. The equation of the curve may then be written by substituting these values in the original equation, or after e has been determined the logarithms of Q and $G - e$ may be plotted.

With two discharge measurements given, e may be obtained from field observations and an approximate logarithmic discharge curve may be drawn through the two plotted positions of Q and $G - e$. Very approximately with a single discharge measurement, e, may be obtained as above and a line drawn through the one plotted point at an angle whose tangent is 1.5 with the log $(G - e)$ axis. Such a method should be used only when a rough estimate of discharge at some particular stage is desired.

The serious objection to plotting a discharge curve from a small number of observations is that it does not provide for the elimination of erroneous measurements. Where accurate records are required a number of observations, covering as wide a range of stage as practicable are essential.

The Area, Mean-depth Discharge Curve.—This method, devised by Stevens,[1] is based upon the assumption that the mean

[1] J. C. Stevens: A Method of Estimating Stream Discharge from a Limited Number of Gagings. *Engineering News*, July 18, 1907.

velocity at the gaging section is given by the Chezy formula and that

$$Q = ac\sqrt{rs} \tag{13}$$

the nomenclature being the same as given on page 189. The mean depth d which is approximately equal to r for most natural streams may be substituted for r in the above equation. If w is the width of the stream

$$d = \frac{a}{w} \tag{14}$$

and writing d for r in equation (13)

$$Q = c\sqrt{s} \times a\sqrt{d} \tag{15}$$

If Q be considered a function of $a\sqrt{d}$ with $c\sqrt{s}$ constant this expression is the equation of a straight line.

From investigations of a number of streams it has been found that when Q is plotted as a function of $a\sqrt{d}$ the points lie very close to a straight line. The apparent errors in assuming c and s to be constants and the exponent of d to be ½ appear to very nearly balance each other.

Fig. 78 shows a discharge curve prepared by this method from the same data that were used for Fig. 77. To facilitate plotting, a curve of $a\sqrt{d}$ is usually constructed, which will include the entire range of stage and after it has been completed points on the discharge curve may be determined directly from gage readings. Values of $a\sqrt{d}$ may be computed for each foot or half-foot interval of gage height, dimensions used in the computations being scaled from a plotted cross-section of the channel. The dotted line indicates the method of locating a discharge measurement of 1757 second-feet, with corresponding gage reading of 3.65 feet, on the $a\sqrt{d}$ discharge curve and transferring the point to the ordinary discharge curve.

The $a\sqrt{d}$ discharge curve intersects the axis of zero discharge at a point where the value of $a\sqrt{d}$ is about 60 corresponding to a gage reading of 0.75. This may be compared to the value of $e = 0.67$ obtained from the logarithmic discharge curve, Fig. 77. The true gage reading of zero discharge is doubtless somewhat below either of these values. However, as two gagings of about 50 second-feet fall on the straight line in each case it is apparent that both the logarithmic and $a\sqrt{d}$ discharge curves are accurate for all but the very smallest discharges. Results obtained from studies of other streams bear out this conclusion. Stevens states that the $a\sqrt{d}$ discharge curve will intersect the zero dis-

charge ordinate at a point corresponding to a depth of flowing water of from 1 to 2 feet.

A discharge curve may be plotted approximately by this method from a limited number of gagings. Theoretically two discharge measurements will determine the position of the line instead of three which are required by the logarithmic method. With a single measurement the line may be roughly located by

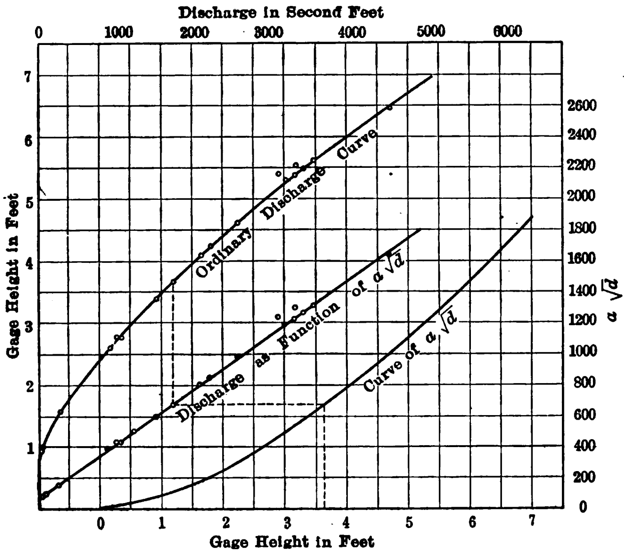


FIG. 78.—Area, mean-depth discharge curve.

drawing it through the plotted point to intersect the ordinate of zero discharge at a value of $a\sqrt{d}$ corresponding to a depth of water from 1 to 2 feet.

A careful comparison of Figs. 77 and 78, shows that the results obtained by the two methods of plotting are practically identical. Either method is believed to be trustworthy provided a few reliable discharge measurements are available. If a question should arise regarding the best method to use in a particular case it will probably be better to use each of them and let one check the other. The logarithmic method has the advantage of giving a simple equation for the discharge curve which may be used in computing the discharge table.

It should be understood that the above discussion refers only to streams having a reasonably uniform cross-section and it does not apply to channels with banks that have abruptly changing slopes. If the stream has a flood plain at a gaging section, the portion of the channel lying outside of the regular banks of the stream should be considered separately.

Discharge Table.—After a discharge curve has been satisfactorily plotted and checked, a discharge table should be prepared. The following is a portion of the discharge table for the Huron River at the Fuller St. station, which gives discharges for each 0.01-foot interval of gage height.

Gage height, feet	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
2.0	531	537	543	548	554	560	566	572	578	584
2.1	590	596	602	608	614	620	626	632	638	644
2.2	651	657	663	669	675	682	688	694	701	707
2.3	713	720	726	732	739	745	752	758	765	771
2.4	778	784	791	797	804	810	817	824	830	837
2.5	844	850	857	864	870	877	884	891	898	904
2.6	911	918	925	932	939	946	953	960	967	974
2.7	981	988	995	1,002	1,009	1,016	1,023	1,030	1,037	1,044
2.8	1,051	1,059	1,066	1,073	1,080	1,087	1,095	1,102	1,109	1,116
2.9	1,124	1,131	1,138	1,146	1,153	1,161	1,168	1,175	1,183	1,190

The completed table should cover the entire range in stage of the stream. Such a table may be used directly without interpolation, and materially reduces the labor of working up daily discharges from the gage records.

The most satisfactory method of computing a discharge table is from the equation of the discharge curve, similar to equation (11*a*), page 269. It will be found necessary to compute discharges by the formula only for each 0.1-foot interval of gage height, the remaining discharges being determined by the method of differences. The first differences will gradually increase while the second differences will decrease slightly with an increase of stage and become very nearly constant for the higher stages. In order to have the quantities in the table correct to the nearest second-foot the computations by differences should be carried out to one or two decimal places, and the results tabulated to the nearest whole number.

A discharge table may be made directly from the discharge

curve, by scaling values from the curve for each 0.1-foot interval of gage height, and interpolating intermediate values. The quantities thus obtained should then be adjusted till the first and second differences vary uniformly. This process will be found to be very tedious, and is not as satisfactory as the method of computing values from the equation of the curve.

Verification of Discharge Curve.—The accuracy of the discharge records obtained at any station depends in a large measure upon the maintenance of a known relation between gage height and discharge. Any conditions of flow which may have a tendency to effect the control should be carefully watched. It is therefore advisable to make occasional gagings of the stream, particularly after floods, to check the discharge curve. If it should be found at any time that a change of channel conditions has affected the relation of stage to discharge it will be necessary to make a new set of gagings and construct a new discharge curve. The time when the use of the new discharge curve should be substituted for the old will be the time at which, in the judgment of the engineer, the change in channel conditions occurred.

Streams with Shifting Beds.—There are certain streams, of which those in southwestern United States are typical, which have continually shifting beds and consequently a continually changing relation between gage height and discharge. To obtain continuous discharge records on such streams discharge measurements should be made every few days. If the stage of the stream does not change rapidly the discharge may be assumed to vary uniformly between successive gagings and intermediate discharges may be interpolated. This method, however, is not satisfactory and it fails entirely for varying rates of change in flow.

Several methods have been suggested for obtaining continuous discharge records from gage readings, but only one, the Stout method, will be described. An average discharge curve is first drawn from the discharge measurements. Then for each discharge measurement the correction, plus or minus, is obtained which must be applied to the gage reading to make it correspond to the approximate discharge curve. These corrections are then plotted for the proper date, as shown in Fig. 79, after which a curve is drawn through the points. The points may be connected simply with the idea of obtaining a smooth curve unless some condition such as a flood on a par-

ticular day might indicate that there had been only a slight change in the channel up to that time. After the curve has been completed, the gage readings for each day may be corrected and these in turn may be used to obtain discharges from the approximate curve or table of discharges.

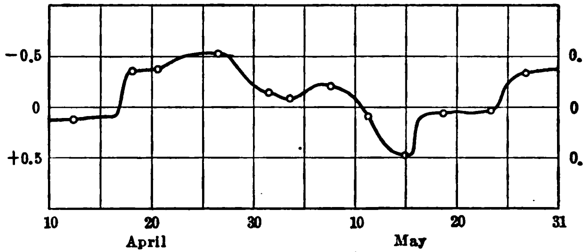


FIG. 79.—Curve for correcting gage readings for changing channel conditions.

Discharge of Streams during Freezing Weather.[1]—The freezing of a stream may or may not affect the relation of gage height to discharge. If the control (see page 259) is free from ice the stream at the gage may be entirely frozen over without changing this relation. As soon, however, as ice forms at the control the water will be backed up and cause a decreased discharge for a given gage height. Ice may collect above or below a control in sufficient quantity to temporarily form a new control. There are three distinct types of ice formation; surface ice, anchor ice, and frazil or slush ice. In any of these forms or in their combined influence ice may cause a backing up effect of the water of a stream.

Anchor ice forms in running water on cold nights when the temperature of the water is below 32°F., adhering to the bed of the river or to some other surface with which the water comes in contact. When the temperature of the water becomes a small fraction of a degree greater than 32°F. the anchor ice becomes loosened from the object to which it is attached, rises to the surface and floats down stream. Frazil or slush ice forms in running water, when the temperature of the water is below 32°F., in the shape of small needles or thin flakes which

[1] This subject is fully discussed in *Water Supply Paper* No. 337 of the U. S. Geological Survey.

may collect in large masses and float on the surface of the stream.

Ice jams may occur at a point in a stream where a swift current enters a body of slack water. The slack water may freeze over while the portion of the stream with the swift current will not freeze but presents a condition favorable for the formation of frazil ice. Two pieces of ice in contact will freeze together almost instantaneously providing the temperature of the thin layer of water between them is below 32°F. Hence the pieces of frazil ice upon coming in contact with the solid ice covering may immediately freeze to it and result in the formation of an ice jam. During protracted cold spells ice jams formed in this manner may cause serious damage from floods due to back water.

Anchor ice may adhere to the bed of the stream at the control and cause a temporary backing up of water. This ice, which forms always at night, will become loosened when the sun's rays strike the water even though the air remains several degrees below freezing temperature. The presence of anchor ice at the control is indicated by a drop in the gage reading during the morning hours and a rise at night.

It is evident that the effect of ice in a stream will always be to cause a greater gage reading for a given discharge than is given by the open-water condition. The gage reading may be affected for comparatively short or intermittent periods, as when anchor ice forms at the control, or for several days or weeks when the obstruction is caused by an ice jam or covering of ice. For the more permanent obstruction the problem of keeping continuous discharge records is quite similar to that described for streams with shifting channels. A careful study of ice conditions and frequent discharge measurements are necessary. Since it is evident that the stage of a stream will not fluctuate greatly during freezing weather the discharge may be considered to vary uniformly between successive gagings if they are not taken too far apart.

A method of correcting gagings, similar to the method for shifting channels illustrated in Fig. 79, may be used for applying a correction to gage readings to make them correspond to the proper discharges for the open-water curve. Such corrections will always be negative. A record of daily temperatures, for the period in question, preferably in the form of a graph

Table 87.

Daily Discharge, in Second-feet, of Sevier River near Gunnison, Utah, for 1910

Day	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1	470	530	715	875	530	100	30	140	44	270	470	330
2	805	550	715	850	590	100	30	140	44	255	715	330
3	782	570	805	828	550	110	30	190	44	240	550	330
4	805	550	900	805	470	100	30	178	80	228	435	330
5	782	550	1,120	715	490	100	30	140	90	215	418	330
6	782	470	1,150	760	470	100	30	120	90	202	418	330
7	715	470	1,410	715	435	80	30	120	120	202	365	300
8	715	470	1,380	670	470	80	30	120	120	202	348	300
9	692	470	1,350	670	400	70	30	100	152	202	330	300
10	670	480	1,300	650	435	60	30	120	152	228	330	285
11	670	490	1,300	590	470	60	30	100	165	228	330	240
12	630	510	1,220	510	400	60	30	315	178	228	315	240
13	590	510	1,200	490	382	60	30	165	152	240	315	240
14	590	510	1,200	470	400	60	30	120	152	240	315	255
15	550	510	1,200	470	365	52	30	120	152	255	315	240
16	715	470	1,200	435	330	60	30	120	152	270	315	240
17	550	510	1,200	435	400	44	30	100	140	285	315	330
18	550	510	1,200	418	300	44	30	90	140	285	300	382
19	550	550	1,180	418	315	44	44	90	178	300	315	382
20	550	550	1,150	418	300	44	37	90	270	300	300	382
21	530	570	1,150	470	315	44	60	80	435	300	315	382
22	530	590	1,180	452	270	44	60	80	435	315	300	380
23	530	590	1,200	400	270	44	60	70	400	315	300	380
24	530	590	1,200	418	202	44	60	70	400	315	300	370
25	510	590	1,200	435	60	44	60	60	400	330	300	370
26	510	610	1,250	435	100	37	110	60	400	330	300	360
27	470	630	1,180	452	190	30	110	60	365	382	315	360
28	470	630	1,000	452	120	30	110	52	330	365	315	360
29	435	....	1,000	452	100	30	120	52	315	400	315	350
30	400	....	950	470	100	30	120	52	285	400	330	350
31	510	....	950	....	100	.....	120	44	.....	400	.....	350

Note.—Daily discharge determined from discharge rating curve fairly well defined. Discharge interpolated for days on which gage was not read. Discharge Dec. 22 to 31 estimated.

Monthly Discharge of Sevier River near Gunnison, Utah, for 1910

[Drainage area, 3,990 square miles]

Month	Discharge in second-feet				Run off		Accuracy
	Maximum	Minimum	Mean	Per square mile	Depth in inches on drainage area	Total in acre-feet	
January......	805	400	600	0.150	0.17	36,900	B
February.....	630	470	537	.135	.14	29,800	B
March.......	1,410	715	1,130	.283	.33	69,500	B
April........	875	400	554	.139	.16	33,000	B
May.........	590	60	333	.083	.10	20,500	B
June.........	110	30	60.2	.015	.02	3,580	B
July.........	120	30	52	.013	.01	3,200	B
August.......	315	44	108	.027	.03	6,640	A
September....	435	44	213	.053	.06	12,700	A
October......	400	202	282	.071	.08	17,300	A
November....	715	300	353	.088	.10	21,000	A
December....	382	240	326	.082	.09	20,000	B
The year...	1,410	30	379	.095	1.29	274,000	

may be valuable in drawing the curve of gage corrections between the known points. After this curve has been completed the gage readings may be corrected and applied to the open-water discharge curve.

Records of Discharge.—Daily discharge records should be tabulated and kept in a form convenient for reference. Table 87 indicates the form adopted by the U. S. Geological Survey.

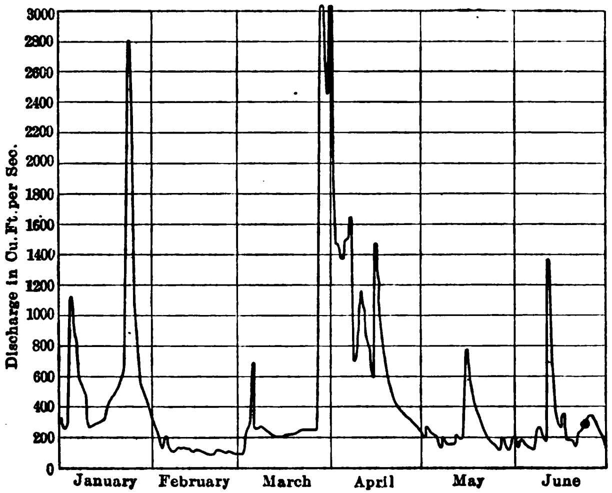


FIG. 80.—Hydrograph.

Hydrographs, Fig. 80, are graphical representations of records of discharge, the ordinates expressing discharges and the abscissas time. They may be plotted continuously or on separate sheets, usually for yearly periods. Hydrographs convey a better mental picture of the discharge of a stream than is possible from tabulated values and, when drawn to a small scale, they are very valuable for reports and other purposes where general conditions only are to be expressed. Hydrographs plotted to a scale of from 1 to 2 inches to the month may be used to advantage in many problems pertaining to stream flow and in connection with the mass diagram, page 294, they may be helpful in storage calculations.

CHAPTER IX

SPECIAL PROBLEMS

Backwater Curve

Backwater curve is the term applied to the profile of the surface of the water in a channel above a dam or other obstruction. The problem may be encountered in either canals or natural streams. When a dam is constructed across a natural stream it may be necessary to determine the flow line for flood discharges in the pond above the dam in order to estimate property damages or to calculate the effect of backwater on a power plant above the dam. The solution here given is general and applies to either natural or artificial channels. The problem as commonly stated gives the discharge and elevation of water surface at the obstruction causing backwater; it being desired to obtain the elevation of water surface at successive points upstream from the obstruction.

The first step in the solution consists of dividing the stream into reaches of such length that a mean cross-section of the reach may be obtained which, when used in the computations, will give results within the desired limits of accuracy. The computations usually start at the obstruction with a known or assumed discharge and corresponding elevation of water surface. The slope through the first reach is then calculated from which the elevation of water surface at the beginning of the second reach may be obtained. This elevation may then be used as a basis for computing the slope in the second reach, which in turn gives data for obtaining the elevation of water surface at the beginning of the third reach. In the same manner the slope of other reaches may be determined until the solution has been carried as far as is desired.

A plan of the channel and data for obtaining as many cross-sections as are desired should be available. Fig. 81 shows a plan, longitudinal section and two typical cross-sections of a natural stream. The plan shows contours from which cross-

sections at any desired points may be obtained. In addition to such contours as many actual elevations as are available should be plotted on the map. This applies especially to elevations of the stream bed which should show clearly the main channel of the stream. The more accurate the data contained on the map the more reliable will be the slope computations. A map of this kind is not necessary for artificial channels of regular form as cross-sections may be readily obtained at any point.

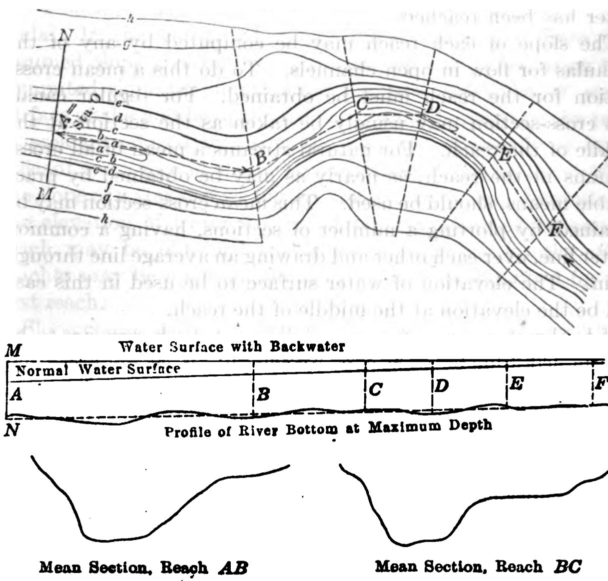


FIG. 81.—Plan, profile. and cross-sections of stream for backwater computations.

The figure shows a dam *MN* constructed between contours *gg*. *AB*, *BC*, *CD*, etc., are successive reaches in which slopes are to be computed. The length of reach to be chosen will depend upon the uniformity of the channel and the rate of slope. In general, the more regular the channel and the smaller the slope the longer the reach that may be chosen. Ordinarily the longer reaches will be taken nearest to the obstruction and become shorter farther upstream. Where sudden changes in cross-

section occur it is generally advisable to take a short reach that extends from just below to just above the place where the change occurs.

The longitudinal section, Fig. 81, shows the general form of the backwater curve. The backwater curve gradually approaches the line of normal water surface and will ultimately become tangent to it. In practical problems it may be assumed that when the slope of the backwater curve becomes approximately parallel to the bed of the stream, the limit of the backwater has been reached.

The slope of each reach may be computed by any of the formulas for flow in open channels. To do this a mean cross-section for the reach must be obtained. For regular canals this cross-section may usually be taken as the section at the middle of the reach. For natural streams a mean of all cross-sections in the reach, as nearly as may be obtained by practicable means, should be used. This mean cross-section may be obtained by plotting a number of sections, having a common center line, over each other and drawing an average line through them. The elevation of water surface to be used in this case will be the elevation at the middle of the reach.

If backwater curves for several different discharges are to be determined, time may be saved by computing several areas and hydraulic radii for the mean cross-sections for each reach, using elevations of water surface chosen arbitrarily within the range of assumed conditions, and from these values drawing area curves and hydraulic radii curves by plotting on cross-section paper elevations for ordinates and areas and hydraulic radii respectively for abscissas. Any values then needed in the computations may be taken from these curves. The areas of plotted cross-sections may be conveniently obtained by means of a planimeter. Where several elevations of water surface are to be considered at any cross-section it will be found convenient to first compute the area for the highest water surface and then, for the next lower water surface, subtract the area between the elevations of the two water surfaces. This subtractive quantity will be equal to the difference in elevation of the two surfaces multiplied by their mean length. The length of wetted perimeter may be scaled from the cross-section. On ordinary river channels the wetted perimeter is equal approximately to the width of the stream plus the maximum depth of water, or more accurately for channels of nearly rectangular

cross-section, it is equal to the width of stream plus 2 times the mean depth.

After obtaining mean cross-sections the first step in the computations is to assume a slope for the reach being considered in order that an elevation of water surface, at the middle of the reach, for the cross-section may be obtained. With this trial elevation decided upon the area and hydraulic radius for the section may be determined and $v = \frac{Q}{a}$ found. The slope of water surface may then be computed by an open-channel formula. If the computed slope differs materially from the assumed slope a second computation may be made, using this computed slope for determining the trial elevation of water surface at the middle of the reach. Usually, however, the error in area introduced by using the assumed slope will be insignificant and a second computation will not be necessary. After the slope of water surface for the first reach has been determined, the elevation of water surface at the beginning of the second reach may be obtained and the computations for the other reaches may be made in the same manner as described for the first reach.

Slope computations may be readily made by means of Manning's formula (page 190), which may be written in the form

$$s = \frac{n^2v^2}{2.2082r^{4/3}} \qquad (1)$$

Values of $\frac{1}{2.2082r^{4/3}}$ for a range of r from 0.1 to 55 feet are given in Table 82, page 222, and by using this table the solution reduces to the simple operation of multiplying the tabulated value corresponding to the given r by $(nv)^2$. The computations may be still farther reduced by using Diagram 2, opposite page 230, for determining s. This diagram will be accurate enough for ordinary backwater calculations.

Engineers who are accustomed to use Kutter's formula for computations of this kind will find that the two formulas give results agreeing very closely. If, however, it has been decided to use a certain value of n with Kutter's formula the corresponding value of n for Manning's formula which will give identical results may be obtained from Table 75, page 204.

It will generally be found more convenient to mark off 100 feet stations on the center line of the channel, beginning with

station 0 at the downstream end of the curve. All elevations should be referred to the same datum, and tied to one or more permanent bench marks.

Preferably the results of computations should be kept in tabular form in order to systematize the work and provide a concise record for future reference. Table 88 is an example of a form which may be used for backwater computations.

It is sometimes desired to determine the height to which water in a stream at a given point may be raised by the construction of a dam or otherwise without backing up the water above a certain elevation at some point farther upstream. In this case the method to be followed in making computations is the same as described above except that they proceed downstream instead of upstream and slope corrections are subtracted instead of added.

In cases where the stream is divided between two channels as in passing around opposite sides of an island, the given discharge is divided by judgment between the two channels. The slope in each with its portion of the discharge is computed and if it is found that the computed slope for one channel gives a greater difference of elevation between the ends of the island than the computed slope for the other channel, the computation is repeated, reducing the proportion of the discharge assumed to pass through the channel which gave the greater difference in elevation and increasing the proportion of discharge for the channel which gave the smaller difference in elevation. This has the effect of increasing the calculated slope in one channel and reducing it in the other. The operation is repeated until the flow is so divided between the two channels that starting with an assumed elevation at one end the calculated elevation at the other end of each channel is the same.

After two complete trial solutions have been made, the following graphical method may be employed to complete the computations. Let Q_1 be one of the trial discharges for either channel and Q_2 the other trial discharge for the same channel. Consider discharges as abscissas and elevations as ordinates. On the ordinate Q_1 plot the elevations obtained for each channel for the trial solution in which Q_1 was used and on the ordinate Q_2 plot the elevations obtained by the other trial solution. The ordinate of the point of intersection of the straight lines connecting the points for each channel will be the approximate 'evation required. The abscissa of the point gives the ap-

TABLE 88.—BACKWATER COMPUTATIONS. $Q = 20{,}000$ SECOND-FEET. ELEVATION OF WATER SURFACE AT DAM = 512.6.

Lower station	Upper station	Length of reach	Elevation at lower end	Trial mean elevation	Trial mean area, a	Hydraulic radius, r	Mean velocity $v = \frac{Q}{a}$	Roughness n	Slope s	Fall in reach	Elevation at upper end of reach
0	53	5,300	512.6	512.9	6,461	11.9	3.09	.030	.00014	.795	513.40
53	56	300	513.40	513.4	5,934	13.1	3.37	.030	.00015	.045	513.44
56	61	500	513.44	513.5	5,607	12.8	3.47	.030	.00015	.075	513.51
61	64	300	513.51	513.6	5,697	8.9	3.51	.030	.00027	.081	513.60
64	75	1,100	513.60	513.7	5,595	13.1	3.57	.030	.00017	.187	513.78
75	101	2,600	513.78	514.1	4,980	9.8	4.02	.030	.00031	.806	514.59
101	108	700	514.59	514.7	4,520	8.3	4.42	.030	.00047	.329	514.92
108	121	1,300	514.92	515.1	4,815	9.1	4.15	.035	.00050	.650	515.57
121	151	3,000	515.57	516.1	5,175	11.4	3.86	.035	.00032	.960	516.53

proximate discharge of the channel for which Q_1 and Q_2 were trial discharges. The values obtained by this method may be checked by slope calculations.

In case a stream has a flood plain which is overflowed during higher stages it is better not to include this portion of the discharge in the computations for the main channel, but to subdivide the flow by judgment between the flood plain and main channel making the calculations in the same manner as for a channel divided by an island, as already described. Trial subdivisions should be repeated until a division of the flow has been found such that the fall on the flood plain in the given reach becomes the same as the fall in the main channel.

As a rule the generally accepted values of coefficients of roughness cannot be followed closely in applying the formulas for flow in open channels, especially in case of low water and in channels subject to backwater from dams. In such channels there is usually more or less slackwater in places along the bottom and sides of the channel, which cannot properly be included as an effective part of the channel. It is usually difficult to eliminate slackwater areas from measured cross-sections and in order that slope computations may, in a measure, allow for this condition it is necessary to use a larger coefficient of roughness. Natural channels may require the use of a coefficient of roughness of 0.040 or 0.050 in cases where the bed and banks are such that the categorical coefficient of roughness would be 0.025 to 0.030. The presence of slackwater may often be detected by the growth of aquatic grass, in which case, even though there is a good current, the coefficient of roughness will be much larger than for a channel free from such obstruction.

It is frequently important to determine whether an existing or proposed dam has caused or will cause a rise in the surface elevation of a stream at some point upstream from the dam. In such cases a profile of the water surface when not influenced by backwater is essential. The best method of obtaining the necessary data is to keep a continuous daily record of stage and discharge at the point in question. If this information is secured before the dam is built it will furnish the best possible evidence as to the natural stage of the stream, and frequently such data cannot be secured after the dam has been built, even by drawing down the water, owing to changes in the channel by silting and the formation of bars at the head of the pond.

Divided Flow in Pipes

An example of this problem is illustrated by Fig. 82. The pipe AB divides at B into the two branches BEC and BFC which reunite at C where they discharge into the pipe CD. Let l, l_1, l_2 and l_3 represent respectively the lengths of pipes AB, BEC, BFC, and CD and d, d_1, d_2 and d_3 and v, v_1, v_2 and v_3 the corresponding diameters and velocities. K_1, K'_1, K''_1, and K'''_1 are friction coefficients (see page 154 and Table 57, page

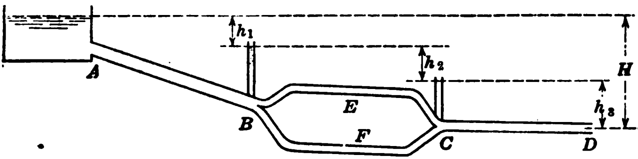


FIG. 82.—Pipe with divided flow.

172). The total head lost in friction from A to B is represented by h_1 from B to C by h_2, from C to D by h_3, and from A to D the total head lost in the system is represented by H. It is apparent that

$$H = h_1 + h_2 + h_3 \tag{2}$$

also, see page 158,

$$H = K_1 \frac{l}{d^{1.25}} \cdot \frac{v^2}{2g} + K'_1 \frac{l_1}{d_1^{1.25}} \cdot \frac{v_1^2}{2g} + K'''_1 \frac{l_3}{d_3^{1.25}} \cdot \frac{v_3^2}{2g} \tag{3}$$

And since the lost head in the two branching pipes must be the same

$$K'_1 \frac{l_1}{d_1^{1.25}} \cdot \frac{v_1^2}{2g} = K''_1 \frac{l_2}{d_2^{1.25}} \cdot \frac{v_2^2}{2g} \tag{4}$$

and

$$v_1 \sqrt{\frac{K'_1 l_1}{d_1^{1.25}}} = v_2 \sqrt{\frac{K''_1 l_2}{d_2^{1.25}}} \tag{5}$$

From the principle of continuity of flow the following relation may be obtained

$$vd^2 = v_1 d_1^2 + v_2 d_2^2 = v_3 d_3^2 \tag{6}$$

Also from equations (5) and (6)

$$v_1 = \frac{vd^2 \sqrt{\frac{K''_1 l_2}{d_2^{1.25}}}}{d_1^2 \sqrt{\frac{K''_1 l_2}{d_2^{1.25}}} + d_2^2 \sqrt{\frac{K'_1 l_1}{d_1^{1.25}}}} \tag{7}$$

$$v_2 = \frac{vd^2\sqrt{\dfrac{K'_1 l_1}{d_1^{1.25}}}}{d_1^2\sqrt{\dfrac{K''_1 l_2}{d_2^{1.25}}} + d_2^2\sqrt{\dfrac{K'_1 l_1}{d_1^{1.25}}}} \tag{8}$$

$$v_3 = \frac{vd^2}{d_3^2} \tag{9}$$

and from equations (3), (7), (8), and (9)

$$H = \frac{v^2}{2g}\left[K_1\frac{l}{d^{1.25}} + K'_1\frac{l_1}{d_1^{1.25}}\left(\frac{d^2\sqrt{\dfrac{K''_1 l_2}{d_2^{1.25}}}}{d_1^2\sqrt{\dfrac{K''_1 l_2}{d_2^{1.25}}} + d_2^2\sqrt{\dfrac{K'_1 l_1}{d_1^{1.25}}}}\right)^2 + K'''_1\frac{l_3}{d_3^{1.25}}\frac{d^4}{d_3^4}\right] \tag{10}$$

From this equation v may be computed, and v_1, v_2 and v_3 may be obtained from equations (7), (8) and (9). Also H may be calculated when the discharge and all dimensions of the pipe system are given. If H and the discharge and all dimensions except one are given the missing dimension may be computed from the above formulas.

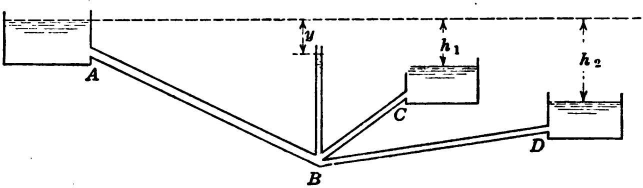


FIG. 83.—Pipe with branches discharging at different elevations.

The use of Table 60 or 61, pages 175 and 178, which give values of $\frac{1}{d^{1.25}}$ will simplify the computations. The values of K_1, K'_1, K''_1 and K'''_1 are to be taken from Table 57, page 172. These values will vary slightly with the velocity, and as they must be chosen from an assumed velocity it may be necessary to make a second solution of the problem after obtaining approximate velocities from the first solution.

Another problem sometimes encountered is illustrated in Fig. 83. AB is a main pipe line which divides at B into the branches

BC and BD. y is the head lost in friction in the pipe AB and h_1 and h_2 represent the total head lost in friction to the outlets C and D respectively. l, l_1 and l_2 are the respective lengths of AB, BC, and BD, and d, d_1 and d_2 and v, v_1 and v_2 are corresponding diameters and velocities. K_1, K'_1, and K''_1 are friction coefficients (see page 154 and Table 57, page 172).

The loss of head due to friction in the two branch pipes is represented by the equations

$$h_1 - y = K'_1 \frac{l_1}{d_1^{1.25}} \cdot \frac{v_1^2}{2g} \text{ and } h_2 - y = K''_1 \frac{l_2}{d_2^{1.25}} \cdot \frac{v_2^2}{2g} \quad (11)$$

and for the main pipe AB

$$y = K_1 \frac{l}{d^{1.25}} \cdot \frac{v^2}{2g} \quad (12)$$

and from the principle of continuity of flow

$$d^2v = d_1^2v_1 + d_2^2v_2 \quad (13)$$

From the relations expressed by the above equations the following formulas may be written

$$2gh_1 = K_1 \frac{l}{d^{1.25}} \left(\frac{d_1^2}{d^2} v_1 + \frac{d_2^2}{d^2} v_2\right)^2 + K'_1 \frac{l_1}{d_1^{1.25}} v_1^2 \quad (14)$$

and

$$2g(h_1 - h_2) = K_1' \frac{l_1}{d_1^{1.25}} v_1^2 - K''_1 \frac{l_2}{d_2^{1.25}} v_2^2 \quad (15)$$

From equations (14) and (15) any two unknown quantities may be determined. If all dimensions of the pipe system and h_1 and h_2 are given v_1 and v_2 may be determined and also the discharges of each of the branch pipes. Similarly d_1 and d_2 may be computed when the other quantities are given. It will usually be found more convenient to solve equation (15) first in order to express one unknown in terms of the other for substituting in equation (14). The values of K_1, K'_1 and K''_1 must first be chosen by trial as described on page 162 and a second solution may be necessary.

A trial method of determining the discharge for a system of pipes, similar to that shown in Fig. 82, is as follows. Assume a discharge and compute h_1 and h_3. Find $H - (h_1 + h_3)$ for a trial value of h_2. With this trial value compute the discharge through pipes E and F. Find the difference between the assumed discharge and the combined discharge of pipes E and F. The true discharge will lie between the assumed discharge and the combined discharge of pipes E and F as computed.

Assume another discharge and again in the same manner find the difference between the assumed discharge and the combined discharge through pipes E and F. Using rectangular coordinates, plot to suitable scale, the differences for each set of computations against the corresponding assumed discharges. Connect the plotted points with a straight line. The point of intersection of this line with the coördinate of zero difference gives approximately the true discharge. A slight error is introduced by assuming a straight line variation between the plotted points. To get a closer result, determine a new difference by the above method using this approximate value of the true discharge. Plot this difference as before and draw a curve through the three plotted points. The intersection of this curve with the coördinate of zero difference should be very close to the true discharge.

A method similar to the above may be employed for determining the discharge through the system of pipes shown in Fig. 83. Q is assumed and y computed after which the combined discharge of pipes BC and BD is obtained. Successive assumptions are then made and the assumed discharges and differences are plotted by the method described above to determine the true discharge.

Short Canals with Free Discharge

A problem frequently encountered in engineering design deals with the flow of water through a short canal having its intake in a comparatively quiet body of water and discharging freely at its lower end. Practical examples of this problem are, a canal excavated around a dam to serve as a spillway for a reservoir or a chute constructed on a steep grade to carry the water in a canal to a lower level.

The problem presents two special cases which necessitate modifications in the method of solution. They are, however, both based upon the principle that there is a certain maximum discharge at the intake which cannot be exceeded. Which of the two methods is to be used depends upon whether the slope of the channel is sufficient to carry this maximum discharge.

The solution for each case is given below. A trapezoidal canal section is assumed in each case, and formulas are derived which are later given in a simplified form for rectangular sections.

Short Canal with Flat Slope.—Fig. 84 shows a longitudinal section and cross-section of the canal. The water enters the canal from a reservoir at the upper end and leaves with free discharge at the lower end. The following nomenclature is used:

D = Depth of water above canal bottom at entrance.
H = Depth of water in canal just above outlet.
h_0 = Lost head at entrance plus velocity head.
v_0 = Mean velocity in upper end of canal.
b = Width of canal bottom.
z = Slope of sides of canal; horizontal to vertical.
l = Length of canal.
s = Slope of water surface in canal.
s_1 = Slope of bottom of canal.
r = Hydraulic radius of cross-section of canal.
C = Coefficient of discharge.

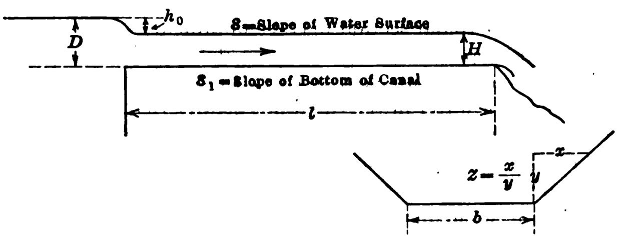


FIG. 84.—Short canal with flat slope.

The value of C will vary from unity for perfect entrance conditions, with well-rounded corners to 0.82 where all corners at entrance to canal are sharp.

The velocity just below the entrance to the canal is given by the formula

$$v_0 = C\sqrt{2gh_0}. \tag{16}$$

Also, letting a represent the area of water section in the upper end of canal

$$Q = av_0 = C\sqrt{2g}h_0^{1/2}(D - h_0)[b + z(D - h_0)] \tag{17}$$

This equation equals zero when $h_0 = 0$ and also when $h_0 = D$. The maximum value of Q, therefore, lies somewhere between these limits. The value of h_0 which will give the maximum

possible value of Q may be obtained by differentiating equation (17) with respect to h_0 and equating to zero. This gives, after reduction, the equation

$$5zh_0^2 - 3(2zD + b)h_0 + (Db + zD^2) = 0 \tag{18}$$

For a rectangular channel z equals zero and for maximum discharge

$$h_0 = \tfrac{1}{3}D \tag{19}$$

Substituting this value of h_0 in formula (17) the resulting formula of discharge for a rectangular section is

$$Q(\text{Maximum}) = 3.087CbD^{3/2} \tag{20}$$

From equation (18) the value of h_0 which gives maximum discharge for a trapezoidal section is

$$h_0 = \frac{3(2zD + b) - \sqrt{16z^2D^2 + 16zDb + 9b^2}}{10z} \tag{21}$$

Substituting this value of h_0 in formula (17) the maximum value of Q for a trapezoidal section may be obtained.

The next step in the solution is to determine whether the slope of the canal is sufficient to carry this maximum discharge with a depth of water in the canal not greater than $D - h_0$. If it is, the discharge of the canal will be equal to the maximum discharge as given by formulas (17) and (21), but if the slope of the canal is not great enough it will cause a backing-up effect and result in a smaller value of h_0 and consequently a smaller discharge.

The lower end of the canal becomes a fall, the discharge over which (see page 142) is given by the formula

$$Q = 5.21H^{1.47}(L + 0.8zH) \tag{22}$$

The last term of this formula disappears for a rectangular section.

To determine the depth of water in the lower end of the canal, assuming the maximum value of Q, substitute this value of Q in formula (22) and solve for H. Then determine

$$s_t = \frac{D - h_0 - H}{l} + s_1 \tag{23}$$

which may be called a trial value of the slope of the canal. For the next step determine the slope necessary to carry the maximum Q as given by formula (17) from one of the formulas

for flow in open channels. Manning's formula (see page 202, also Table 82, page 222) may be written in the form

$$s = \frac{v^2 n^2}{2.2082 r^{4/3}} \tag{24}$$

In this formula r and v may usually be taken as the hydraulic radius and velocity respectively midway between the entrance and outlet to the canal where the depth of water equals $\frac{1}{2}(D - h_0 + H)$. In the case of long canals where there is a material difference in the depths of water at the two ends of the canal it may be necessary to compute the slope of water surface in accordance with the method described for backwater curves (page 278), but usually the slope computed from a section midway between the ends of the canal will cause an inappreciable error in the result.

Considering formulas (23) and (24) if $s_t > s$ the discharge through the canal will be the maximum Q given by formula (17). If $s_t < s$ or negative a value of h_0 less than the value for maximum discharge must be assumed when new trial values of Q, H, s_t and s may be computed by formulas (17), (22), (23) and (24) respectively. Additional trials may be made in the same manner and the process should be continued until $s_t = s$ or until satisfied that the result is close enough for the purpose.

Canal with Steep Slope.—In this case, the discharge is the maximum Q as given by formula (17). The canal having a steep slope, the velocity of water in the canal will be continually accelerated until the slope of the canal is just sufficient to overcome the friction loss due to the velocity. As commonly encountered in practice, Q is given and the problem is to get the dimensions of channel at successive points along the canal required to carry the given quantity of water.

The first step is to determine h_0 and the dimensions of the entrance to the canal. Assume Q, D, and z to be given, which is the common condition. By substituting these values in equations (17) and (21), b and h_0 may be determined. If the channel is rectangular h_0 is given by equation (19) and b, by equation (20). The depth of water in the upper end of the canal is $D - h_0$.

The next step in the solution is to determine dimensions of the channel at successive points along the canal. This problem is illustrated in Fig. 85. A, B, C, etc. are short reaches of the canal to be designed, and dimensions of cross-sections of channel

between reaches A and B, B and C, etc. are to be determined. Computations for each reach are made independently, the cross-section at the lower end of reach A being first determined, then the cross-section at the lower end of reach B and so on.

The following nomenclature will be used.

l = Length of reach considered.
s_1 = Slope of bottom of canal.
h_1 = Fall of water surface in reach considered.
H_1 = Loss of head in reach due to friction.
d_0 = Depth of water in upper end of reach.
d_1 = Depth of water in lower end of reach.
b_0 = Width of canal bottom at upper end of reach.
b_1 = Width of canal bottom at lower end of reach.
v_0 = Mean velocity of water at upper end of reach.
v_1 = Mean velocity of water at lower end of reach.
r = Hydraulic radius of section at middle of reach.
z = Slope of sides of canal.
n = Coefficient in Manning's formula.

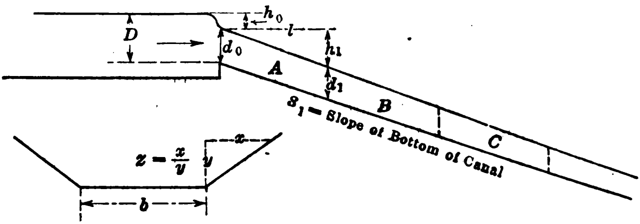


FIG. 85.—Short canal with steep slope.

Referring to Fig. 85 the following equation is obtained directly from Bernoulli's theorem:

$$h_1 + \frac{v_0^2}{2g} = H_1 + \frac{v_1^2}{2g} \qquad (25)$$

From Manning's formula (page 190)

$$v = \frac{1.486}{n} r^{2/3} s^{1/2} = \frac{1.486}{n} r^{2/3} \left(\frac{H_1}{l}\right)^{1/2} \qquad (26)$$

and approximately, putting $v = \frac{1}{2}(v_0 + v_1)$

$$H_1 = \frac{l n^2 (v_0 + v_1)^2}{8.83 r^{4/3}} \qquad (27)$$

Substituting this value of H_1, equation (25) may be written

$$h_1 + \frac{v_0^2}{2g} - \frac{l n^2 (v_0 + v_1)^2}{8.83 r^{4/3}} - \frac{v_1^2}{2g} = 0 \qquad (28)$$

In equation (28) h_1, v_0, v_1 and r may be expressed in terms of b_0, b_1, d_0, d_1 and Q and in this manner the following equation has been derived:

$$d_0 + s_1 l - d_1 + \frac{Q^2}{2gd_0^2(b_0 + zd_0)^2} - \frac{Q^2}{2gd_1^2(b_1 + zd_1)^2} - \frac{ln^2Q^2}{8.83}\left(\frac{1}{d_0(b_0 + zd_0)} + \frac{1}{d_1(b_1 + zd_1)}\right)^2 \times \left(\frac{2(b_0 + b_1) + 4(d_0 + d_1)\sqrt{1 + z^2}}{(d_0 + d_1)[(b_0 + b_1) + z(d_0 + d_1)]}\right)^{4/3} = 0 \quad (29)$$

In equation (29) b_1 and d_1 are the only unknown quantities. Assuming one of these quantities the other may be calculated. Probably a better way is to state b_1 in terms of d_1, as for example $b_1 = 2d_1$ or $b_1 = 3d_1$ according to the general form of cross-section that is desired. If it is planned to have a channel of uniform width and determine the depth of water at different points $b_1 = b_0$ becomes constant and only d_1 is unknown. Likewise, the width of channel at different points may be determined for a constant depth of water. For a channel of rectangular cross-section $z = 0$ and formula (29) becomes simplified. In all cases formula (29) must be solved by substituting trial values. The last term, which is the correction for friction, is usually a comparatively small quantity for the upper reaches and may be neglected in the first trial solution. The value of b_1 or d_1 thus obtained will be slightly too small and a somewhat larger value should be used for substitution in the complete formula. After the section at the lower end of the first reach has been determined, because of the fact that the channel is becoming smaller, it should not be difficult to make a fairly close estimate of the dimension to substitute in the formula for the first trial solution for the next reach.

Probably the most valuable special application of formula (29) is to channels having a rectangular cross-section, and constant depth of water. In this case $z = 0$, and $d_0 = d_1 = d$ (a constant) and b_1, the width at the lower end of successive reaches, is the only quantity to be determined. Under these conditions the formula reduces to

$$s_1 l d^2 + \frac{Q^2}{2gb_0^2} - \frac{Q^2}{2gb_1^2} - \frac{ln^2Q^2}{8.83}\left(\frac{1}{b_0} + \frac{1}{b_1}\right)^2\left(\frac{1}{d} + \frac{4}{b_0 + b_1}\right)^{4/3} = 0 \quad (30)$$

The dimensions of a channel for any form of cross-section may be obtained approximately by first determining cross-sections by formula (30), then for any form of section not

rectangular determine a section of the required shape having approximately the same area as the rectangular section. For a trapezoidal section the area should be a little larger and for a semicircular section the area should be a little smaller than for the rectangular section.

A channel carrying water at an accelerating velocity will, if extended far enough, approach a condition of uniform velocity where the sectional area of the channel will be constant. In the case of comparatively long channels it may be advisable to compute this minimum section in order to know the limit to which the result is approaching. This limit will be reached when the velocity becomes great enough to cause a frictional resistance that will overcome the slope of the channel. The minimum section may be computed by any of the open-channel formulas. Using Manning's formula the following relation exists

$$Q = \frac{1.486s^{1/2}[d(b + zd)]^{5/3}}{n(b + 2d\sqrt{1 + z^2})^{2/3}} \tag{31}$$

or if $z = 0$

$$Q = \frac{1.486s^{1/2}(db)^{5/3}}{n(b + 2d)^{2/3}} \tag{32}$$

With either b (width) or d (depth) given in equation (31) or (32), the other may be determined. The equation must be solved by substituting trial values.

The Mass Diagram for Storage Problems

The flow of natural streams is always subject to more or less daily as well as seasonal fluctuation. It is not an unusual condition for the maximum flow of streams to be as much as 100 times greater than the minimum flow. This condition, in many cases, retards the full economic development of rivers for purposes requiring a uniform rate of flow, or a varying use at certain specified rates.

It is possible to regulate the discharge of certain rivers by means of artificial storage, dependent upon the availability of sites where suitable reservoirs may be economically constructed. In connection with the investigation of storage possibilities of any stream two general types of problems may be encountered. It may be required to determine the storage necessary to provide for a use of water at a uniform rate or at certain speci-

fied rates, or the storage capacity being given, it may be required to determine the available supply of water based upon given requirements as to rate or rates of flow.

Storage problems may be readily solved by means of the mass diagram, a method first described by Rippl.[1] The

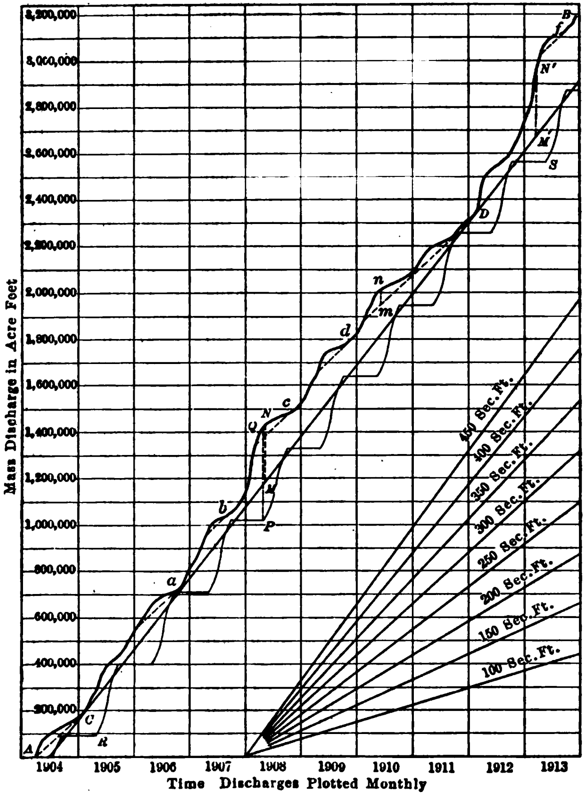


Fig. 86.—Mass diagram.

method of applying the principle of the mass diagram is shown by the example given in the following pages. Fig. 86 shows a mass curve of discharge data for the Huron River near Geddes,

[1] *Proc.* Inst. Civ. Eng., vol. 71, p. 279.

Table 89.—Discharge Data of Huron River at Geddes

Year and month	Mean discharge, second-feet	Total discharge, acre-feet	Total discharge corrected, acre-feet	Mass discharge, acre-feet
1904				
April	1,068	64,080	63,750	63,750
May	404	25,050	24,720	88,470
June	225	13,500	13,170	101,640
July	130	8,060	7,730	109,370
August	139	8,618	8,288	117,658
September	188	11,280	10,950	128,608
October	251	15,562	15,392	144,000
November	167	10,020	9,850	153,850
December	161	9,982	9,810	163,660
1905				
January	204	12,660	12,490	176,150
February	170	9,520	9,350	185,500
March	750	46,500	46,330	231,830
April	668	30,100	29,770	271,600
May	606	37,600	37,270	308,870
June	1,083	64,980	64,650	373,520
July	399	24,750	24,420	397,940
August	297	18,400	18,070	416,010
September	260	15,600	15,270	431,280
October	361	22,400	22,230	453,510
November	454	27,240	27,070	480,580
December	488	30,250	30,080	510,660
1906				
January	685	42,490	42,320	552,980
February	426	23,860	23,690	576,670
March	515	31,940	31,770	608,440
April	620	37,200	36,870	645,310
May	454	28,200	27,870	673,180
June	322	19,320	18,990	692,170
July	148	9,180	8,850	701,020
August	156	9,680	9,350	710,370
September	84	5,040	4,710	715,080
October	139	8,620	8,450	723,530
November	272	16,320	16,150	739,680
December	447	27,700	27,530	767,210
1907				
January	980	60,760	60,590	827,800
February	386	21,600	21,430	849,230
March	719	44,600	44,430	893,660
April	859	51,540	51,270	944,870
May	804	49,800	49,470	994,340
June	410	24,600	24,270	1,018,610
July	240	14,890	14,560	1,033,170
August	138	8,560	8,230	1,041,400
September	221	13,260	12,930	1,064,330
October	316	19,560	19,390	1,073,720
November	362	21,720	21,550	1,095,270
December	452	28,020	27,850	1,123,120

Mich., for the years 1904 to 1914 inclusive. Table 89 is an extract from the data and computations on which this mass diagram is based.

The second column of Table 89 gives the mean monthly discharges in second-feet. The third column contains monthly discharges in acre-feet obtained by multiplying the mean monthly discharge by two times the number of days in the month. The fourth column is obtained by deducting estimated seepage and evaporation losses from the quantities given in the third column. The amount of seepage loss depends upon the geological formation of the basin in which the reservoir is located, and this matter should be given the most careful consideration in each particular case. The evaporation loss will vary with the area of exposed water surface, the season of the year, the humidity of the atmosphere, the temperature, the velocity of the wind and other factors. Mean values of evaporation from free water surfaces in different localities are given in Table 90, page 298.

The last column of Table 89 gives the total discharges in acre-feet, corrected for evaporation and seepage losses, from April 1, 1904, up to the end of each month. The irregular line *ACNDB*, Fig. 86, is the curve plotted from these total discharges, and is called the mass curve. Any point on this mass curve represents the total flow in acre-feet, from the beginning of the period to the date given by the corresponding abscissa and the slope of a tangent to the line at this point indicates the rate of flow in second-feet. Straight lines on the diagram indicate a uniform flow, and the slope of such lines indicates the rate of flow. This rate of flow may be obtained by dividing the amount of rise in acre-feet for a given period by two times the number of days in the period. The sloping lines at the lower right-hand side of the diagram show the slopes for the different rates of flow indicated.

The straight line, *CMDM′*, tangent to the two lowest points of the mass curve Fig. 86, gives the maximum uniform flow that may be provided by the stream on the assumption of adequate storage. The maximum ordinate *MN* between this line, hereinafter referred to as the *use line*, and the mass curve, gives the storage that will be necessary to provide for this maximum rate of flow. Scaling from the diagram it is found that a storage capacity of approximately 245,000 acre-

TABLE 90.—MONTHLY AND YEARLY EVAPORATIONS FROM WATER SURFACES

Location	Evaporation in inches												
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Boston, Mass.	0.96	1.05	1.70	2.97	4.46	5.54	5.98	5.50	4.12	3.16	2.25	1.51	39.20
Rochester, N. Y.	0.52	0.54	1.33	2.62	3.93	4.94	5.47	5.30	4.15	3.16	1.45	1.13	34.54
Mt. Hope, N. Y.	1.27	1.26	2.35	2.97	3.64	4.40	5.11	4.73	3.63	2.65	1.70	1.56	35.27
Birmingham, Ala.	1.50	1.50	2.25	4.45	5.91	7.28	7.36	7.34	6.00	4.00	2.25	1.50	51.34
California, Ohio	1.00	1.50	2.50	4.12	5.07	6.21	7.20	7.26	5.63	3.00	1.50	1.00	45.99
Klamath, Ore.	0.50	1.25	3.57	6.64	7.15	6.99	8.01	9.21	6.13	2.50	1.00	0.50	53.45
N. Yakima Wash.	1.75	2.50	6.25	7.91	8.36	8.90	10.74	9.41	5.51	3.15	2.00	1.50	67.96
Minidoka, Idaho	2.25	2.50	4.00	7.00	11.21	12.31	15.00	13.50	11.00	8.50	5.75	3.50	96.52
Granite Reef, Ariz.	4.25	4.40	5.25	7.00	9.50	12.00	12.75	12.50	11.00	8.31	6.56	4.22	97.74
Salton Sea, Cal.	3.61	5.01	6.75	9.00	11.00	13.50	14.77	12.53	12.40	9.20	6.21	4.67	108.65
Kingsbury, Cal.	0.77	1.25	2.46	2.56	3.39	5.80	7.55	8.65	6.48	4.05	2.12	1.19	46.27
Independence, Cal.	1.66	2.42	4.52	6.87	8.63	10.00	9.45	8.10	6.07	3.87	2.49	1.37	65.45
Emdrup, Denmark	0.70	0.50	0.90	2.00	3.70	5.40	5.20	4.40	2.60	1.30	0.70	0.50	27.90
Lee Bridge, England	0.75	0.60	1.07	2.10	2.75	3.14	3.44	2.85	1.61	1.06	0.67	0.57	20.61
Cape Colony, So. Africa	4.57	5.05	3.40	1.79	1.20	1.81	1.77	1.94	2.68	4.11	5.09	5.65	30.06

feet will be required to provide a maximum uniform flow of 424 second-feet.

The foregoing results are based upon the assumption that the reservoir is empty on the date indicated by the point *C*. From this point water flows into the reservoir at the rates indicated by the mass curve and flows out of the reservoir at the uniform rate indicated by the use line *CMDM'*. The amount of water remaining in the reservoir on any date is given by the length of the ordinate intercepted by the two lines. At *D* all of the water has been drawn from the reservoir. From *D* the reservoir begins to fill again and (assuming $MN = M'N'$ to be the capacity of the reservoir) on the date when the ordinate between the use line and mass curve becomes *M'N'* the reservoir is full. From this point until a tangent to the mass curve becomes parallel to the use line, water will be wasted from the reservoir and the discharge will be greater than that indicated by the use line.

To find the storage capacity required to provide for a minimum flow of say 300 second-feet, draw lines, with a slope corresponding to this rate of flow, tangent to the mass curve at the low points *a*, *b*, *c*, *d*, *e*, etc., extending them downward till they intersect the mass curve. Then the maximum ordinate between any of these use lines and the mass curve, *mn*, will give the required storage capacity. In this case the surplus water, during the high-water season, after the reservoir is full will be wasted and the available flow will be greater than 300 second-feet until the point is reached where the tangent to the mass curve becomes parallel to the use line.

The problem is similar when it is desired to find the rate of flow which can be secured with a storage reservoir of given capacity. Lines of different slopes may be tried at the low points of the mass curve until a slope is found which gives a maximum ordinate corresponding to the given capacity. It can usually be told from inspection about where the maximum ordinate will occur, and the problem may then be solved approximately by drawing in this ordinate as closely as possible to its correct position and from a point a distance below the mass curve equal to the given storage capacity extend upward a tangent to the mass curve. The slope of this line will be the approximate rate of flow required. This work should be carefully checked and lines should be drawn at the slope thus de-

termined tangent to other low points on the mass curve in order to make sure that no greater ordinate may be found.

Other types of storage problems may be encountered but in general they may be solved by an application of the above principles. In cases where the storage is limited and the problem becomes one of storing a portion of the flow that occurs during high stages to supplement the following low-water flows, it may be more convenient to plot separate mass curves to a larger scale for each year or two-year period. This provides for a more detailed study and results may be scaled with greater accuracy. In order to obtain a general conception of the problem, however, it will generally be found advantageous to first prepare a mass diagram of the entire discharge data.

In many cases water will not be used at a uniform rate. This is especially true of irrigation where water is required only throughout the growing season and during the remainder of the year it must be stored if the entire flow of the stream is to be conserved. The line *RPS*, Fig. 86, is the use line for the Huron River assuming that the total discharge for the period is to be used at the following rates:

May	10 per cent.
June	25 per cent.
July	30 per cent.
August	25 per cent.
September	10 per cent.

Assuming that the same quantity of water will be required each year, the available yearly supply will be equal approximately to that obtained for the maximum uniform flow, or from the data given for the Huron River it will be very nearly equal to a uniform flow of 424 second-feet or a total yearly flow of 310,000 acre-feet.

The use line, for a non-uniform rate of use must be drawn so as to be tangent to the mass curve at two points the same as for uniform use. In doing this care must be taken to see that each point of the use line comes directly over the time to which it pertains. A simple method of procedure is to first plot the mass curve and then on a piece of tracing paper, using the same scale, plot a trial use line. Then place the latter over the former and see if the use line can be so placed that each point will be

over the proper time and at the same time be tangent to the mass curve at two points. If this cannot be done, the correction can be determined and a new use line may be drawn and applied to the mass curve in the same manner. A second trial will usually give a use line which will fulfil the above requirements and thus give the maximum yearly supply of water available. The storage required will be the maximum ordinate between the mass curve and use line. For the problem given this storage is represented by the ordinate *PQ* and equals 390,000 acre-feet.

Other problems involving a non-uniform rate of use such as are presented by a limited storage capacity, or when a quantity of water less than the maximum discharge is required may be readily solved by an application of the above principles.

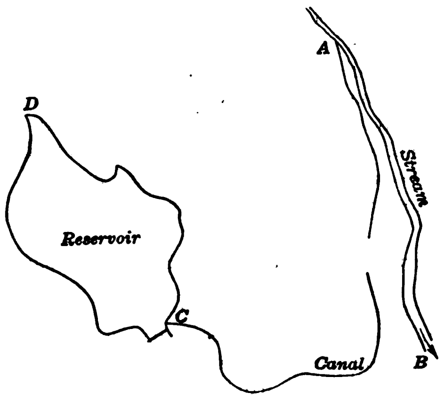


FIG. 87.—Reservoir with supply canal.

A special case where the mass diagram may be used to advantage is in the determination of the capacity of supply canal to feed a reservoir not tributary to the stream supplying the water. The conditions of this problem may be seen from Fig. 87. *AB* is a stream which supplies the water, to be stored in the reservoir *CD*. The canal *AC* carries water from the stream to the reservoir. The annual consumption of water from the reservoir and available discharge from the stream for a period

of years are given. The required capacities of canal and storage reservoir are to be determined.

In this case the quantities which determine the use line are given so that it may be plotted once for all, preferably on transparent paper. The seepage and evaporation losses in the canal and reservoir should be considered as additional water consumed and correction for same should be included in the use line. The next step is to assume a capacity for the canal, and plot a mass curve of water diverted into the canal, using the same scale as that chosen for the use line but on a separate sheet. When the available supply of water in the stream is equal to or greater than the capacity of the canal, the capacity of the canal will be the quantity diverted, otherwise this quantity will be the available flow of the stream.

After this mass curve has been plotted, a trial should be made by the method described above, to determine whether the use curve can be so moved as to be tangent to it at two points. If not, a new capacity of canal must be assumed and a new mass curve plotted and the above process repeated until the use line and the mass curve may be placed so as to be tangent to each other at two points. The last assumed capacity of the supply canal will be the required capacity and the maximum ordinate between the mass curve and use line will be the required storage capacity.

Determination of Reservoir Spillway Capacity

In designing a dam for storage purposes, it is essential to provide a spillway of sufficient capacity to prevent the water surface in the reservoir, even under extreme flood conditions, from rising above a certain fixed safe elevation. In calculating the required spillway capacity for a reservoir, it is necessary to consider the worst possible flood conditions for the locality and assume such flood to discharge into the reservoir when full. Under these conditions water will begin to flow over the spillway as soon as the first flood waters enter the reservoir. The reservoir produces an equalizing effect upon the flood, so that the maximum discharge over the spillway will be something less than the maximum flood discharge. The extent of this equalizing effect increases with the size of the reservoir and for reservoirs that are small in comparison with the discharge, may be inappreciable.

The solution here given, first suggested by Jacob,[1] is general and may be applied to any data. Areas of water surface corresponding to different depths of water passing over the spillway are generally taken from topographic maps. Maximum flood discharges may be estimated from a study of records for the stream in question and other streams in the locality, or it may be investigated from the standpoint of run-off to be expected from the severest storms. It is characteristic of floods that they rise quite rapidly to a peak and then recede more slowly.

A concrete example involving the principles of the solution of this problem is given below. A similar method may be employed to solve any problems of this kind.

Statement of Problem.—A stream tributary to a reservoir has the following flood wave:

Date and time	Second-feet
May 10, 9 A.M.	40
May 10, 12 Noon	400
May 10, 5 P.M.	1,200
May 11, 12 Midnight	900
May 11, 12 Noon	650
May 12, 12 Midnight	450
May 12, 12 Noon	250
May 13, 12 Midnight	150
May 13, 12 Noon	100

At 9 A.M., May 10, the water in the reservoir was at the elevation of the crest of the spillway. The spillway is a weir of ogee section, 20 feet long, the discharge over which is given by the formula $Q = 3.4LH^{3/2}$. The area of the reservoir is 1000 acres at the spillway crest, which increases by 30 acres for each 1-foot rise in elevation. Determine the maximum depth of water that passes over the spillway.

Solution of Problem.—1. Prepare a table showing the discharge in second-feet for each time given in the problem and also the discharge in acre-feet for each period and the total flood discharge in acre-feet at the end of each period as follows:

[1] C. C. Jacob; Computing the Size of a Reservoir Spillway. *Engineering News*, June 13, 1912.

Date and time	Second-feet	Acre-feet	Acre-feet mass
May 10, 9 A.M.	40		
May 10, 12 Noon	400	55	55
May 10, 5 P.M.	1,200	333	388
May 11, 12 Midnight	900	612	1,000
May 11, 12 Noon	650	775	1,775
May 12, 12 Midnight	450	550	2,325
May 12, 12 Noon	250	350	2,675
May 13, 12 Midnight	150	200	2,875
May 13, 12 Noon	100	125	3,000

2. Prepare a table showing depth of water above spillway crest in the reservoir and the corresponding areas of flow line, volumes of water above crest of spillway and discharge over spillway.

Depth above spillway crest, feet	Area of flow line, acres	Volume above spillway crest, acre-feet	Discharge over spillway, second-feet
0.0	1,000	0	0.0
0.5	1,015	504	24.0
1.0	1,030	1,015	68.0
1.5	1,045	1,534	124.0
2.0	1,060	2,060	190.7
2.5	1,075	2,594	268.8
3.0	1,090	3,135	353.3

3. From the last two columns of the preceding table plot a curve to suitable scale, which will show the relation between volume of water above crest of spillway in acre-feet and discharge over spillway in second-feet, *EF*, Fig. 88.

4. From the data in the first table plot a mass curve, to suitable scale, *PM*, Fig. 88, with total flow of river in acre-feet for the ordinates and time in days for the abscissas. The vertical scale should be such that the total discharge in acre-feet may be plotted and the horizontal scale should provide for the entire flood period.

From the same origin *P* and with the same coördinates plot a mass curve *PN* representing the total discharge over the spillway. This must be done by a method of approximations, proceeding in the following manner: Assume that after some

reasonable short period from the beginning of the flood, say at 4 P.M. on May 10, the total discharge over the spillway has been 100 acre-feet. This is represented at A, and means that

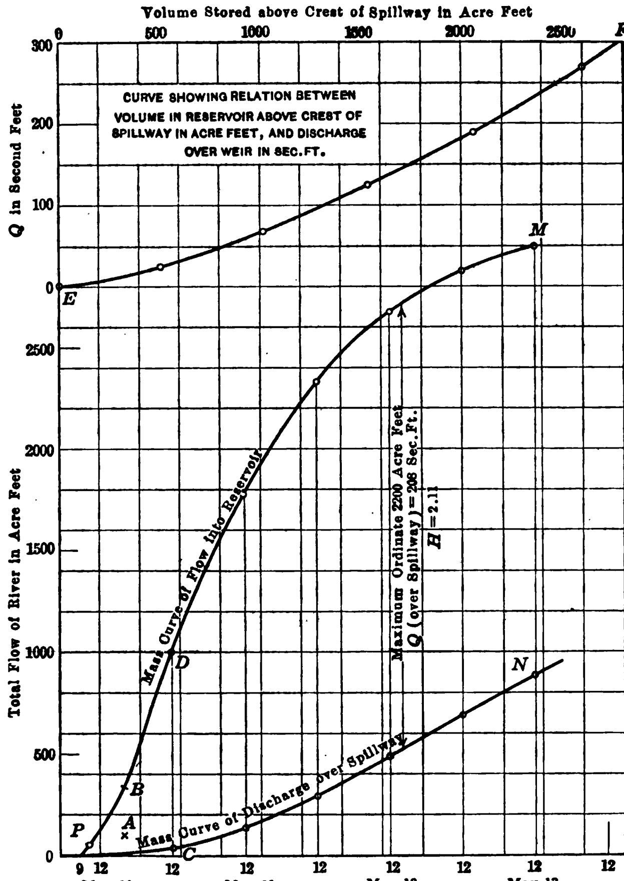


FIG. 88.—Determination of reservoir spillway capacity.

the mass curve of discharge over the spillway should pass through this point, if the assumption is correct.

To find the correct position of the point from this assumed

position, determine the length of the ordinate AB, which gives as the assumed volume of water in the reservoir approximately 210 acre-feet. Then from the curve EF determine the discharge in second-feet over the spillway corresponding to a volume of 210 acre-feet in the reservoir. This is approximately 8 second-feet. Since 8 second-feet is the discharge at 4 P.M. and the discharge at 9 A.M. was 0 second-feet, the average for the period is approximately 4 second-feet and the total discharge for the 7-hour period is $2\frac{1}{3}$ acre-feet.

It thus appears that the first assumption that 100 acre-feet had discharged over the weir was much too great and consequently the volume of water remaining in the reservoir and represented by AB was correspondingly too small and the resulting discharge over the weir (8 second-feet or a total of $2\frac{1}{3}$ acre-feet) is too small. The correct total discharge over the weir for the period, therefore, lies somewhere between $2\frac{1}{3}$ acre-feet and 100 acre-feet, but is obviously much closer to the former.

For the second assumption, therefore, we may assume 4 acre-feet for the total discharge over the weir, and in the same manner as above determine 3 acre-feet for the recomputed value, which is sufficiently close to the assumed discharge. Plotting 3 acre-feet for the total discharge over the spillway at 4 P.M., May 10, and connecting this point with zero discharge at 9 A.M., gives the first section of the mass curve. The following table, which gives only the final trial solution indicates the method of making computations.

Date and time	Assumed mass discharge over spillway, acre-feet	Volume in reservoir above spillway	Discharge over spillway, second-feet	Discharge for period, acre-feet	Computed mass discharge over spillway, acre-feet
May 10, 9 A.M.					
May 10, 4 P.M.	4	306	11	3	3
May 10, 12 Midnight	40	960	62	24	27
May 11, 12 Noon	120	1,600	140	101	128
May 11, 12 Midnight	280	2,050	187	161	289
May 12, 12 Noon	460	2,210	210	199	488
May 12, 12 Midnight	700	2,180	207	208	696
May 13, 12 Noon	900	2,100	195	201	897

The secon. point on the curve may be taken at 12 o'clock midnight between May 10 and 11. Since the general direction of the curve can now be seen the assumed position of this point C should ordinarily be made closely enough so that one trial will be sufficient. In the same manner as above the ordinate CD is found to represent a volume of about 960 acre-feet, for which the corresponding spillway discharge is 62 second-feet. Since the discharge at the last point of observation was 11 feet the average discharge for this period is 36.5 second-feet or a total for the period of 24 acre-feet. The grand total discharge over the weir since the beginning of the flood is found by adding the total for the period to the grand total obtained at the end of the last period, which gives, in this case, 3 acre-feet plus 24 acre-feet, or 27 acre-feet. This determines the location of a second point on the mass curve.

Similarly other points may be found and the curve extended as far as desired. The maximum vertical ordinate between the two mass curves evidently gives the maximum volume of water above the spillway crest, which equals 2160 acre-feet. From curve EF the corresponding discharge over the weir is found to be 208 second-feet and the head on the weir necessary to provide this discharge, determined from the weir formula, is 2.11 feet. The time of maximum discharge is 2 P.M., May 12.

It will be noted that the maximum discharge over the spillway is only 17 per cent. of the maximum flood discharge. The reason for this small percentage is because of the short duration of the flood wave. With a longer flood period the discharge over the weir will continue to increase and gradually approach the discharge of the stream.

Use of Logarithms

The common or Briggs logarithms are the only ones used in ordinary mathematical calculations. In this system the logarithm of a number is the power to which 10 must be raised to equal the number. Thus the logarithms of 1, 10, 100, 1000, 10,000, etc., are respectively 0, 1, 2, 3, 4, etc., and the logarithms of 0.1, 0.01, 0.001, ... and 0 are respectively -1, -2, -3, ... and $-\infty$. It is apparent that all numbers greater than unity have positive logarithms and those less than unity have negative logarithms.

The logarithms of all numbers which are not integral powers of 10 are fractional and consist of an integer called the char-

acteristic and a decimal fraction which is termed the mantissa. The logarithms of numbers greater than unity have characteristics one less than the number of places to the left of the decimal point, and for a given sequence of figures the mantissas are equal. The following examples will illustrate:

$$\begin{aligned}
\text{Logarithm of } 4.45 &= 0.64836\\
\text{Logarithm of } 44.5 &= 1.64836\\
\text{Logarithm of } 445 &= 2.64836\\
\text{Logarithm of } 4450 &= 3.64836
\end{aligned}$$

Negative logarithms, that is, the logarithms of numbers less than unity, are generally expressed with negative characteristics and positive mantissas. This gives a common mantissa for a given sequence of figures regardless of whether the number is greater or less than unity. A minus sign over the characteristic indicates that the characteristic is negative and the mantissa positive. Frequently 10 is added to such logarithms to make the whole logarithm positive, it being understood that the logarithm is 10 less than indicated. The following examples illustrate different methods of expressing the logarithms of numbers less than unity:

$$\begin{aligned}
\text{Logarithm of } 4.45 &= +0.64836 = 0.64836 = 0.64836\\
\text{Logarithm of } 0.445 &= -0.35164 = \bar{1}.64836 = 9.64836 - 10\\
\text{Logarithm of } 0.0445 &= -1.35164 = \bar{2}.64836 = 8.64836 - 10\\
\text{Logarithm of } 0.00445 &= -2.35164 = \bar{3}.64836 = 7.64836 - 10\\
\text{Logarithm of } 0.000445 &= -3.35164 = \bar{4}.64836 = 6.64836 - 10
\end{aligned}$$

If the logarithm of a number is subtracted from zero the difference is called the cologarithm of the number. The cologarithm of a number is thus the logarithm of its reciprocal. It is evident also that the cologarithm of a number less than unity is positive. The following table gives logarithms and corresponding cologarithms of various numbers, the mantissas in all cases being positive and the characteristics positive or negative as required.

Number	Logarithm	Cologarithm
4,450	3.64836	$\bar{4}.35164$
445	2.64836	$\bar{3}.35164$
44.5	1.64836	$\bar{2}.35164$
4.45	0.64836	$\bar{1}.35164$
0.445	$\bar{1}.64836$	0.35164
0.0445	$\bar{2}.64836$	1.35164
0.00445	$\bar{3}.64836$	2.35164
0.000445	$\bar{4}.64836$	3.35164

Tables of logarithms are of great value in simplifying the operations of multiplication, division, involution and evolution and in evaluating expressions containing fractional exponents, they are indispensable. Ordinarily logarithmic tables contain only the mantissas, as the value of the characteristic can be readily determined from the position of the decimal point. Table 91, page 311, contains logarithms of numbers from 1 to 10,000 to five places of decimals, and Table 92, page 329, gives corresponding cologarithms.

Below are indicated the processes to be followed in the solution of a few fundamental problems involving the use of logarithms. The words logarithm and cologarithm are abbreviated to log and colog respectively.

$$\log abc = \log a + \log b + \log c$$
$$\log \frac{ab}{c} = \log a + \log b - \log c = \log a + \log b + \operatorname{colog} c$$
$$\log b^x = x \log b = -x \operatorname{colog} b$$
$$\log \frac{1}{b^x} = -x \log b = x \operatorname{colog} b$$
$$\log ab^x = \log a + x \log b = \log a - x \operatorname{colog} b$$
$$\log \frac{a}{b^x} = \log a - x \log b = \log a + x \operatorname{colog} b$$

Owing to the fact that it is very confusing to multiply logarithms having a negative characteristic and positive mantissa, it will be found much simpler to use cologarithms as indicated above when a number less than unity is to be raised to any power. The following numerical examples indicate the simplest method of solving such problems.

Problem.—Given $y = 3.127 \times 0.04156^{0.217}$; to determine y.

$$\begin{aligned} \log y &= \log 3.127 - 0.217 \operatorname{colog} 0.04156 \\ \log y &= 0.49513 - 0.217 \times 1.38132 \\ &= 0.19538 \\ y &= 1.568 \end{aligned}$$

Problem.—Given $y = \dfrac{0.07658}{0.1917^{0.251}}$; to determine y.

$$\begin{aligned} \log y &= \log 0.07658 + 0.251 \operatorname{colog} 0.1917 \\ &= \bar{2}.88412 + 0.251 \times 0.71738 \\ &= \bar{1}.06418 \\ y &= 0.1159 \end{aligned}$$

CHAPTER X

GENERAL REFERENCE TABLES

By familiarizing himself with the location and purpose of the various tables contained in this volume, the engineer will be able to simplify the processes involved in hydraulic calculations. Following each chapter in the preceding pages the tables pertaining to the subject matter treated in that chapter are given. Tables which will be found useful in general hydraulic computations are included in the following pages.

Many problems may be worked with sufficient accuracy with a slide rule. A log log slide rule will be found particularly convenient in evaluating hydraulic formulas. Where greater accuracy is required logarithms should be used. In order to save time and reduce the liability of error the engineer should use logarithms in the place of direct methods of calculation whenever possible. Table 91, page 311 contains five place logarithms of numbers up to 10,000 and Table 92, page 329 gives the corresponding cologarithms of numbers. The latter table will be found especially useful in problems involving mixed operations of multiplication and division and in raising to any powers numbers less than unity. The principle of logarithms and typical problems involving their use are given on pages 307 to 309.

Tables 93, 94, and 95, pages 347 to 352 inclusive, give the natural trigonometric functions to 5 decimal places for intervals of 10 minutes. Table 96, page 353, contains the squares, cubes, square roots, cube roots, and reciprocals of numbers from 1 to 1000. Table 97, page 373, gives the square roots of numbers from 1000 to 10,000, with an interval of 10, to 2 decimal places. Tables 98 and 99, pages 375 and 377 give respectively circumferences and areas of circles, with diameters up to 10, for intervals of .01 and Tables 100 and 101, pages 379 and 381, give circumferences and areas, for diameters of circles up to 100, for intervals of ⅛. Ordinarily Tables 60 and 61, pages 175 and 178 will be found more convenient for determining areas of circles in the solution of pipe problems than Tables 99 and 101.

Table 91.—Logarithms of Numbers

N.	L. 0	1	2	3	4	5	6	7	8	9
100	00 000	043	087	130	173	217	260	303	346	389
101	432	475	518	561	604	647	689	732	775	817
102	860	903	945	988	*030	*072	*115	*157	*199	*242
103	01 284	326	368	410	452	494	536	578	620	662
104	703	745	787	828	870	912	953	995	*036	*078
105	02 119	160	202	243	284	325	366	407	449	490
106	531	572	612	653	694	735	776	816	857	898
107	938	979	*019	*060	*100	*141	*181	*222	*262	*302
108	03 342	383	423	463	503	543	583	623	663	703
109	743	782	822	862	902	941	981	*021	*060	*100
110	04 139	179	218	258	297	336	376	415	454	493
111	532	571	610	650	689	727	766	805	844	883
112	922	961	999	*038	*077	*115	*154	*192	*231	*269
113	05 308	346	385	423	461	500	538	576	614	652
114	690	729	767	805	843	881	918	956	994	*032
115	06 070	108	145	183	221	258	296	333	371	408
116	446	483	521	558	595	633	670	707	744	781
117	819	856	893	930	967	*004	*041	*078	*115	*151
118	07 188	225	262	298	335	372	408	445	482	518
119	555	591	628	664	700	737	773	809	846	882
120	918	954	990	*027	*063	*099	*135	*171	*207	*243
121	08 279	314	350	386	422	458	493	529	565	600
122	636	672	707	743	778	814	849	884	920	955
123	991	*026	*061	*096	*132	*167	*202	*237	*272	*307
124	09 342	377	412	447	482	517	552	587	621	656
125	691	726	760	795	830	864	899	934	968	*003
126	10 037	072	106	140	175	209	243	278	312	346
127	380	415	449	483	517	551	585	619	653	687
128	721	755	789	823	857	890	924	958	992	*025
129	11 059	093	126	160	193	227	261	294	327	361
130	394	428	461	494	528	561	594	628	661	694
131	727	760	793	826	860	893	926	959	992	*024
132	12 057	090	123	156	189	222	254	287	320	352
133	385	418	450	483	516	548	581	613	646	678
134	710	743	775	808	840	872	905	937	969	*001
135	13 033	066	098	130	162	194	226	258	290	322
136	354	386	418	450	481	513	545	577	609	640
137	672	704	735	767	799	830	862	893	925	956
138	988	*019	*051	*082	*114	*145	*176	*208	*239	*270
139	14 301	333	364	395	426	457	489	520	551	582
140	613	644	675	706	737	768	799	829	860	891
141	922	953	983	*014	*045	*076	*106	*137	*168	*198
142	15 229	259	290	320	351	381	412	442	473	503
143	534	564	594	625	655	685	715	746	776	806
144	836	866	897	927	957	987	*017	*047	*077	*107
145	16 137	167	197	227	256	286	316	346	376	406
146	435	465	495	524	554	584	613	643	673	702
147	732	761	791	820	850	879	909	938	967	997
148	17 026	056	085	114	143	173	202	231	260	289
149	319	348	377	406	435	464	493	522	551	580
150	609	638	667	696	725	754	782	811	840	869
N.	L. 0	1	2	3	4	5	6	7	8	9

P. P.

	44	43	42
1	4.4	4.3	4.2
2	8.8	8.6	8.4
3	13.2	12.9	12.6
4	17.6	17.2	16.8
5	22.0	21.5	21.0
6	26.4	25.8	25.2
7	30.8	30.1	29.4
8	35.2	34.4	33.6
9	39.6	38.7	37.8

	41	40	39
1	4.1	4.0	3.9
2	8.2	8.0	7.8
3	12.3	12.0	11.7
4	16.4	16.0	15.6
5	20.5	20.0	19.5
6	24.6	24.0	23.4
7	28.7	28.0	27.3
8	32.8	32.0	31.2
9	36.9	36.0	35.1

	38	37	36
1	3.8	3.7	3.6
2	7.6	7.4	7.2
3	11.4	11.1	10.8
4	15.2	14.8	14.4
5	19.0	18.5	18.0
6	22.8	22.2	21.6
7	26.6	25.9	25.2
8	30.4	29.6	28.8
9	34.2	33.3	32.4

	35	34	33
1	3.5	3.4	3.3
2	7.0	6.8	6.6
3	10.5	10.2	9.9
4	14.0	13.6	13.2
5	17.5	17.0	16.5
6	21.0	20.4	19.8
7	24.5	23.8	23.1
8	28.0	27.2	26.4
9	31.5	30.6	29.7

	32	31	30
1	3.2	3.1	3.0
2	6.4	6.2	6.0
3	9.6	9.3	9.0
4	12.8	12.4	12.0
5	16.0	15.5	15.0
6	19.2	18.6	18.0
7	22.4	21.7	21.0
8	25.6	24.8	24.0
9	28.8	27.9	27.0

P. P.

Table 91 (*Continued*)
Logarithms of Numbers

N.	L. 0	1	2	3	4	5	6	7	8	9
150	17 609	638	667	696	725	754	782	811	840	869
151	898	926	955	984	*013	*041	*070	*099	*127	*156
152	18 184	213	241	270	298	327	355	384	412	441
153	469	498	526	554	583	611	639	667	696	724
154	752	780	808	837	865	893	921	949	977	*005
155	19 033	061	089	117	145	173	201	229	257	285
156	312	340	368	396	424	451	479	507	535	562
157	590	618	645	673	700	728	756	783	811	838
158	866	893	921	948	976	*003	*030	*058	*085	*112
159	20 140	167	194	222	249	276	303	330	358	385
160	412	439	466	493	520	548	575	602	629	656
161	683	710	737	763	790	817	844	871	898	925
162	952	978	*005	*032	*059	*085	*112	*139	*165	*192
163	21 219	245	272	299	325	352	378	405	431	458
164	484	511	537	564	590	617	643	669	696	722
165	748	775	801	827	854	880	906	932	958	985
166	22 011	037	063	089	115	141	167	194	220	246
167	272	298	324	350	376	401	427	453	479	505
168	531	557	583	608	634	660	686	712	737	763
169	789	814	840	866	891	917	943	968	994	*019
170	23 045	070	096	121	147	172	198	223	249	274
171	300	325	350	376	401	426	452	477	502	528
172	553	578	603	629	654	679	704	729	754	779
173	805	830	855	880	905	930	955	980	*005	*030
174	24 055	080	105	130	155	180	204	229	254	279
175	304	329	353	378	403	428	452	477	502	527
176	551	576	601	625	650	674	699	724	748	773
177	797	822	846	871	895	920	944	969	993	*018
178	25 042	066	091	115	139	164	188	212	237	261
179	285	310	334	358	382	406	431	455	479	503
180	527	551	575	600	624	648	672	696	720	744
181	768	792	816	840	864	888	912	935	959	983
182	26 007	031	055	079	102	126	150	174	198	221
183	245	269	293	316	340	364	387	411	435	458
184	482	505	529	553	576	600	623	647	670	694
185	717	741	764	788	811	834	858	881	905	928
186	951	975	998	*021	*045	*068	*091	*114	*138	*161
187	27 184	207	231	254	277	300	323	346	370	393
188	416	439	462	485	508	531	554	577	600	623
189	646	669	692	715	738	761	784	807	830	852
190	875	898	921	944	967	989	*012	*035	*058	*081
191	28 103	126	149	171	194	217	240	262	285	307
192	330	353	375	398	421	443	466	488	511	533
193	556	578	601	623	646	668	691	713	735	758
194	780	803	825	847	870	892	914	937	959	981
195	29 003	026	048	070	092	115	137	159	181	203
196	226	248	270	292	314	336	358	380	403	425
197	447	469	491	513	535	557	579	601	623	645
198	667	688	710	732	754	776	798	820	842	863
199	885	907	929	951	973	994	*016	*038	*060	*081
200	30 103	125	146	168	190	211	233	255	276	298
N.	L 0	1	2	3	4	5	6	7	8	9

P. P.

	29	28
1	2.9	2.8
2	5.8	5.6
3	8.7	8.4
4	11.6	11.2
5	14.5	14.0
6	17.4	16.8
7	20.3	19.6
8	23.2	22.4
9	26.1	25.2

	27	26
1	2.7	2.6
2	5.4	5.2
3	8.1	7.8
4	10.8	10.4
5	13.5	13.0
6	16.2	15.6
7	18.9	18.2
8	21.6	20.8
9	24.3	23.4

	25
1	2.5
2	5.0
3	7.5
4	10.0
5	12.5
6	15.0
7	17.5
8	20.0
9	22.5

	24	23
1	2.4	2.3
2	4.8	4.6
3	7.2	6.9
4	9.6	9.2
5	12.0	11.5
6	14.4	13.8
7	16.8	16.1
8	19.2	18.4
9	21.6	20.7

	22	21
1	2.2	2.1
2	4.4	4.2
3	6.6	6.3
4	8.8	8.4
5	11.0	10.5
6	13.2	12.6
7	15.4	14.7
8	17.6	16.8
9	19.8	18.9

P. P.

Table 91 (*Continued*)
Logarithms of Numbers

N.	L. 0	1	2	3	4	5	6	7	8	9
200	30 103	125	146	168	190	211	233	255	276	298
201	320	341	363	384	406	428	449	471	492	514
202	535	557	578	600	621	643	664	685	707	728
203	750	771	792	814	835	856	878	899	920	942
204	963	984	*006	*027	*048	*069	*091	*112	*133	*154
205	31 175	197	218	239	260	281	302	323	345	366
206	387	408	429	450	471	492	513	534	555	576
207	597	618	639	660	681	702	723	744	765	785
208	806	827	848	869	890	911	931	952	973	994
209	32 015	035	056	077	098	118	139	160	181	201
210	222	243	263	284	305	325	346	366	387	408
211	428	449	469	490	510	531	552	572	593	613
212	634	654	675	695	715	736	756	777	797	818
213	838	858	879	899	919	940	960	980	*001	*021
214	33 041	062	082	102	122	143	163	183	203	224
215	244	264	284	304	325	345	365	385	405	425
216	445	465	486	506	526	546	566	586	606	626
217	646	666	686	706	726	746	766	786	806	826
218	846	866	885	905	925	945	965	985	*005	*025
219	34 044	064	084	104	124	143	163	183	203	223
220	242	262	282	301	321	341	361	380	400	420
221	439	459	479	498	518	537	557	577	596	616
222	635	655	674	694	713	733	753	772	792	811
223	830	850	869	889	908	928	947	967	986	*005
224	35 025	044	064	083	102	122	141	160	180	199
225	218	238	257	276	295	315	334	353	372	392
226	411	430	449	468	488	507	526	545	564	583
227	603	622	641	660	679	698	717	736	755	774
228	793	813	832	851	870	889	908	927	946	965
229	984	*003	*021	*040	*059	*078	*097	*116	*135	*154
230	36 173	192	211	229	248	267	286	305	324	342
231	361	380	399	418	436	455	474	493	511	530
232	549	568	586	605	624	642	661	680	698	717
233	736	754	773	791	810	829	847	866	884	903
234	922	940	959	977	996	*014	*033	*051	*070	*088
235	37 107	125	144	162	181	199	218	236	254	273
236	291	310	328	346	365	383	401	420	438	457
237	475	493	511	530	548	566	585	603	621	639
238	658	676	694	712	731	749	767	785	803	822
239	840	858	876	894	912	931	949	967	985	*003
240	38 021	039	057	075	093	112	130	148	166	184
241	202	220	238	256	274	292	310	328	346	364
242	382	399	417	435	453	471	489	507	525	543
243	561	578	596	614	632	650	668	686	703	721
244	739	757	775	792	810	828	846	863	881	899
245	917	934	952	970	987	*005	*023	*041	*058	*076
246	39 094	111	129	146	164	182	199	217	235	252
247	270	287	305	322	340	358	375	393	410	428
248	445	463	480	498	515	533	550	568	585	602
249	620	637	655	672	690	707	724	742	759	777
250	794	811	829	846	863	881	898	915	933	950
N.	L. 0	1	2	3	4	5	6	7	8	9

P. P.

	22	21
1	2.2	2.1
2	4.4	4.2
3	6.6	6.3
4	8.8	8.4
5	11.0	10.5
6	13.2	12.6
7	15.4	14.7
8	17.6	16.8
9	19.8	18.9

	20
1	2.0
2	4.0
3	6.0
4	8.0
5	10.0
6	12.0
7	14.0
8	16.0
9	18.0

	19
1	1.9
2	3.8
3	5.7
4	7.6
5	9.5
6	11.4
7	13.3
8	15.2
9	17.1

	18
1	1.8
2	3.6
3	5.4
4	7.2
5	9.0
6	10.8
7	12.6
8	14.4
9	16.2

	17
1	1.7
2	3.4
3	5.1
4	6.8
5	8.5
6	10.2
7	11.9
8	13.6
9	15.3

P. P.

Table 91 (*Continued*)
Logarithms of Numbers

N.	L. 0	1	2	3	4	5	6	7	8	9
250	39 794	811	829	846	863	881	898	915	933	950
251	967	985	*002	*019	*037	*054	*071	*088	*106	*123
252	40 140	157	175	192	209	226	243	261	278	295
253	312	329	346	364	381	398	415	432	449	466
254	483	500	518	535	552	569	586	603	620	637
255	654	671	688	705	722	739	756	773	790	807
256	824	841	858	875	892	909	926	943	960	976
257	993	*010	*027	*044	*061	*078	*095	*111	*128	*145
258	41 162	179	196	212	229	246	263	280	296	313
259	330	347	363	380	397	414	430	447	464	481
260	497	514	531	547	564	581	597	614	631	647
261	664	681	697	714	731	747	764	780	797	814
262	830	847	863	880	896	913	929	946	963	979
263	996	*012	*029	*045	*062	*078	*095	*111	*127	*144
264	42 160	177	193	210	226	243	259	275	292	308
265	325	341	357	374	390	406	423	439	455	472
266	488	504	521	537	553	570	586	602	619	635
267	651	667	684	700	716	732	749	765	781	797
268	813	830	846	862	878	894	911	927	943	959
269	975	991	*008	*024	*040	*056	*072	*088	*104	*120
270	43 136	152	169	185	201	217	233	249	265	281
271	297	313	329	345	361	377	393	409	425	441
272	457	473	489	505	521	537	553	569	584	600
273	616	632	648	664	680	696	712	727	743	759
274	775	791	807	823	838	854	870	886	902	917
275	933	949	965	981	996	*012	*028	*044	*059	*075
276	44 091	107	122	138	154	170	185	201	217	232
277	248	264	279	295	311	326	342	358	373	389
278	404	420	436	451	467	483	498	514	529	545
279	560	576	592	607	623	638	654	669	685	700
280	716	731	747	762	778	793	809	824	840	855
281	871	886	902	917	932	948	963	979	994	*010
282	45 025	040	056	071	086	102	117	133	148	163
283	179	194	209	225	240	255	271	286	301	317
284	332	347	362	378	393	408	423	439	454	469
285	484	500	515	530	545	561	576	591	606	621
286	637	652	667	682	697	712	728	743	758	773
287	788	803	818	834	849	864	879	894	909	924
288	939	954	969	984	*000	*015	*030	*045	*060	*075
289	46 090	105	120	135	150	165	180	195	210	225
290	240	255	270	285	300	315	330	345	359	374
291	389	404	419	434	449	464	479	494	509	523
292	538	553	568	583	598	613	627	642	657	672
293	687	702	716	731	746	761	776	790	805	820
294	835	850	864	879	894	909	923	938	953	967
295	982	997	*012	*026	*041	*056	*070	*085	*100	*114
296	47 129	144	159	173	188	202	217	232	246	261
297	276	290	305	319	334	349	363	378	392	407
298	422	436	451	465	480	494	509	524	538	553
299	567	582	596	611	625	640	654	669	683	698
300	712	727	741	756	770	784	799	813	828	842
N.	L. 0	1	2	3	4	5	6	7	8	9

P. P.

	18
1	1.8
2	3.6
3	5.4
4	7.2
5	9.0
6	10.8
7	12.6
8	14.4
9	16.2

	17
1	1.7
2	3.4
3	5.1
4	6.8
5	8.5
6	10.2
7	11.9
8	13.6
9	15.3

	16
1	1.6
2	3.2
3	4.8
4	6.4
5	8.0
6	9.6
7	11.2
8	12.8
9	14.4

	15
1	1.5
2	3.0
3	4.5
4	6.0
5	7.5
6	9.0
7	10.5
8	12.0
9	13.5

	14
1	1.4
2	2.8
3	4.2
4	5.6
5	7.0
6	8.4
7	9.8
8	11.2
9	12.6

TABLE 91 (*Continued*)
LOGARITHMS OF NUMBERS

N.	L. 0	1	2	3	4	5	6	7	8	9
300	47 712	727	741	756	770	784	799	813	828	842
301	857	871	885	900	914	929	943	958	972	986
302	48 001	015	029	044	058	073	087	101	116	130
303	144	159	173	187	202	216	230	244	259	273
304	287	302	316	330	344	359	373	387	401	416
305	430	444	458	473	487	501	515	530	544	558
306	572	586	601	615	629	643	657	671	686	700
307	714	728	742	756	770	785	799	813	827	841
308	855	869	883	897	911	926	940	954	968	982
309	996	*010	*024	*038	*052	*066	*080	*094	*108	*122
310	49 136	150	164	178	192	206	220	234	248	262
311	276	290	304	318	332	346	360	374	388	402
312	415	429	443	457	471	485	499	513	527	541
313	554	568	582	596	610	624	638	651	665	679
314	693	707	721	734	748	762	776	790	803	817
315	831	845	859	872	886	900	914	927	941	955
316	969	982	996	*010	*024	*037	*051	*065	*079	*092
317	50 106	120	133	147	161	174	188	202	215	229
318	243	256	270	284	297	311	325	338	352	365
319	379	393	406	420	433	447	461	474	488	501
320	515	529	542	556	569	583	596	610	623	637
321	651	664	678	691	705	718	732	745	759	772
322	786	799	813	826	840	853	866	880	893	907
323	920	934	947	961	974	987	*001	*014	*028	*041
324	51 055	068	081	095	108	121	135	148	162	175
325	188	202	215	228	242	255	268	282	295	308
326	322	335	348	362	375	388	402	415	428	441
327	455	468	481	495	508	521	534	548	561	574
328	587	601	614	627	640	654	667	680	693	706
329	720	733	746	759	772	786	799	812	825	838
330	851	865	878	891	904	917	930	943	957	970
331	983	996	*009	*022	*035	*048	*061	*075	*088	*101
332	52 114	127	140	153	166	179	192	205	218	231
333	244	257	270	284	297	310	323	336	349	362
334	375	388	401	414	427	440	453	466	479	492
335	504	517	530	543	556	569	582	595	608	621
336	634	647	660	673	686	699	711	724	737	750
337	763	776	789	802	815	827	840	853	866	879
338	892	905	917	930	943	956	969	982	994	*007
339	53 020	033	046	058	071	084	097	110	122	135
340	148	161	173	186	199	212	224	237	250	263
341	275	288	301	314	326	339	352	364	377	390
342	403	415	428	441	453	466	479	491	504	517
343	529	542	555	567	580	593	605	618	631	643
344	656	668	681	694	706	719	732	744	757	769
345	782	794	807	820	832	845	857	870	882	895
346	908	920	933	945	958	970	983	995	*008	*020
347	54 033	045	058	070	083	095	108	120	133	145
348	158	170	183	195	208	220	233	245	258	270
349	283	295	307	320	332	345	357	370	382	394
350	407	419	432	444	456	469	481	494	506	518
N.	L. 0	1	2	3	4	5	6	7	8	9

P. P.

	15
1	1.5
2	3.0
3	4.5
4	6.0
5	7.5
6	9.0
7	10.5
8	12.0
9	13.5

	14
1	1.4
2	2.8
3	4.2
4	5.6
5	7.0
6	8.4
7	9.8
8	11.2
9	12.6

	13
1	1.3
2	2.6
3	3.9
4	5.2
5	6.5
6	7.8
7	9.1
8	10.4
9	11.7

	12
1	1.2
2	2.4
3	3.6
4	4.8
5	6.0
6	7.2
7	8.4
8	9.6
9	10.8

TABLE 91 (*Continued*)
LOGARITHMS OF NUMBERS

N.	L. 0	1	2	3	4	5	6	7	8	9
850	54 407	419	432	444	456	469	481	494	506	518
851	531	543	555	568	580	593	605	617	630	642
852	654	667	679	691	704	716	728	741	753	765
853	777	790	802	814	827	839	851	864	876	888
854	900	913	925	937	949	962	974	986	998	*011
855	55 023	035	047	060	072	084	096	108	121	133
856	145	157	169	182	194	206	218	230	242	255
857	267	279	291	303	315	328	340	352	364	376
858	388	400	413	425	437	449	461	473	485	497
859	509	522	534	546	558	570	582	594	606	618
860	630	642	654	666	678	691	703	715	727	739
861	751	763	775	787	799	811	823	835	847	859
862	871	883	895	907	919	931	943	955	967	979
863	991	*003	*015	*027	*038	*050	*062	*074	*086	*098
864	56 110	122	134	146	158	170	182	194	205	217
865	229	241	253	265	277	289	301	312	324	336
866	348	360	372	384	396	407	419	431	443	455
867	467	478	490	502	514	526	538	549	561	573
868	585	597	608	620	632	644	656	667	679	691
869	703	714	726	738	750	761	773	785	797	808
870	820	832	844	855	867	879	891	902	914	926
871	937	949	961	972	984	996	*008	*019	*031	*043
872	57 054	066	078	089	101	113	124	136	148	159
873	171	183	194	206	217	229	241	252	264	276
874	287	299	310	322	334	345	357	368	380	392
875	403	415	426	438	449	461	473	484	496	507
876	519	530	542	553	565	576	588	600	611	623
877	634	646	657	669	680	692	703	715	726	738
878	749	761	772	784	795	807	818	830	841	852
879	864	875	887	898	910	921	933	944	955	967
880	978	990	*001	*013	*024	*035	*047	*058	*070	*081
881	58 092	104	115	127	138	149	161	172	184	195
882	206	218	229	240	252	263	274	286	297	309
883	320	331	343	354	365	377	388	399	410	422
884	433	444	456	467	478	490	501	512	524	535
885	546	557	569	580	591	602	614	625	636	647
886	659	670	681	692	704	715	726	737	749	760
887	771	782	794	805	816	827	838	850	861	872
888	883	894	906	917	928	939	950	961	973	984
889	995	*006	*017	*028	*040	*051	*062	*073	*084	*095
890	59 106	118	129	140	151	162	173	184	195	207
891	218	229	240	251	262	273	284	295	306	318
892	329	340	351	362	373	384	395	406	417	428
893	439	450	461	472	483	494	506	517	528	539
894	550	561	572	583	594	605	616	627	638	649
895	660	671	682	693	704	715	726	737	748	759
896	770	780	791	802	813	824	835	846	857	868
897	879	890	901	912	923	934	945	956	966	977
898	988	999	*010	*021	*032	*043	*054	*065	*076	*086
899	60 097	108	119	130	141	152	163	173	184	195
900	206	217	228	239	249	260	271	282	293	304
N.	L. 0	1	2	3	4	5	6	7	8	9

P. P.

	13
1	1.3
2	2.6
3	3.9
4	5.2
5	6.5
6	7.8
7	9.1
8	10.4
9	11.7

	12
1	1.2
2	2.4
3	3.6
4	4.8
5	6.0
6	7.2
7	8.4
8	9.6
9	10.8

	11
1	1.1
2	2.2
3	3.3
4	4.4
5	5.5
6	6.6
7	7.7
8	8.8
9	9.9

	10
1	1.0
2	2.0
3	3.0
4	4.0
5	5.0
6	6.0
7	7.0
8	8.0
9	9.0

TABLE 91 (*Continued*)
LOGARITHMS OF NUMBERS

N.	L. 0	1	2	3	4	5	6	7	8	9
400	60 206	217	228	239	249	260	271	282	293	304
401	314	325	336	347	358	369	379	390	401	412
402	423	433	444	455	466	477	487	498	509	520
403	531	541	552	563	574	584	595	606	617	627
404	638	649	660	670	681	692	703	713	724	735
405	746	756	767	778	788	799	810	821	831	842
406	853	863	874	885	895	906	917	927	938	949
407	959	970	981	991	*002	*013	*023	*034	*045	*055
408	61 066	077	087	098	109	119	130	140	151	162
409	172	183	194	204	215	225	236	247	257	268
410	278	289	300	310	321	331	342	352	363	374
411	384	395	405	416	426	437	448	458	469	479
412	490	500	511	521	532	542	553	563	574	584
413	595	606	616	627	637	648	658	669	679	690
414	700	711	721	731	742	752	763	773	784	794
415	805	815	826	836	847	857	868	878	888	899
416	909	920	930	941	951	962	972	982	993	*003
417	62 014	024	034	045	055	066	076	086	097	107
418	118	128	138	149	159	170	180	190	201	211
419	221	232	242	252	263	273	284	294	304	315
420	325	335	346	356	366	377	387	397	408	418
421	428	439	449	459	469	480	490	500	511	521
422	531	542	552	562	572	583	593	603	613	624
423	634	644	655	665	675	685	696	706	716	726
424	737	747	757	767	778	788	798	808	818	829
425	839	849	859	870	880	890	900	910	921	931
426	941	951	961	972	982	992	*002	*012	*022	*033
427	63 043	053	063	073	083	094	104	114	124	134
428	144	155	165	175	185	195	205	215	225	236
429	246	256	266	276	286	296	306	317	327	337
430	347	357	367	377	387	397	407	417	428	438
431	448	458	468	478	488	498	508	518	528	538
432	548	558	568	579	589	599	609	619	629	639
433	649	659	669	679	689	699	709	719	729	739
434	749	759	769	779	789	799	809	819	829	839
435	849	859	869	879	889	899	909	919	929	939
436	949	959	969	979	988	998	*008	*018	*028	*038
437	64 048	058	068	078	088	098	108	118	128	137
438	147	157	167	177	187	197	207	217	227	237
439	246	256	266	276	286	296	306	316	326	335
440	345	355	365	375	385	395	404	414	424	434
441	444	454	464	473	483	493	503	513	523	532
442	542	552	562	572	582	591	601	611	621	631
443	640	650	660	670	680	689	699	709	719	729
444	738	748	758	768	777	787	797	807	816	826
445	836	846	856	865	875	885	895	904	914	924
446	933	943	953	963	972	982	992	*002	*011	*021
447	65 031	040	050	060	070	079	089	099	108	118
448	128	137	147	157	167	176	186	196	205	215
449	225	234	244	254	263	273	283	292	302	312
450	321	331	341	350	360	369	379	389	398	408
N.	L. 0	1	2	3	4	5	6	7	8	9

P. P.

	11
1	1.1
2	2.2
3	3.3
4	4.4
5	5.5
6	6.6
7	7.7
8	8.8
9	9.9

	10
1	1.0
2	2.0
3	3.0
4	4.0
5	5.0
6	6.0
7	7.0
8	8.0
9	9.0

	9
1	0.9
2	1.8
3	2.7
4	3.6
5	4.5
6	5.4
7	6.3
8	7.2
9	8.1

TABLE 91 (*Continued*)
LOGARITHMS OF NUMBERS

N.	L. 0	1	2	3	4	5	6	7	8	9
450	65 321	331	341	350	360	369	379	389	398	408
451	418	427	437	447	456	466	475	485	495	504
452	514	523	533	543	552	562	571	581	591	600
453	610	619	629	639	648	658	667	677	686	696
454	706	715	725	734	744	753	763	772	782	792
455	801	811	820	830	839	849	858	868	877	887
456	896	906	916	925	935	944	954	963	973	982
457	992	*001	*011	*020	*030	*039	*049	*058	*068	*077
458	66 087	096	106	115	124	134	143	153	162	172
459	181	191	200	210	219	229	238	247	257	266
460	276	285	295	304	314	323	332	342	351	361
461	370	380	389	398	408	417	427	436	445	455
462	464	474	483	492	502	511	521	530	539	549
463	558	567	577	586	596	605	614	624	633	642
464	652	661	671	680	689	699	708	717	727	736
465	745	755	764	773	783	792	801	811	820	829
466	839	848	857	867	876	885	894	904	913	922
467	932	941	950	960	969	978	987	997	*006	*015
468	67 025	034	043	052	062	071	080	089	099	108
469	117	127	136	145	154	164	173	182	191	201
470	210	219	228	237	247	256	265	274	284	293
471	302	311	321	330	339	348	357	367	376	385
472	394	403	413	422	431	440	449	459	468	477
473	486	495	504	514	523	532	541	550	560	569
474	578	587	596	605	614	624	633	642	651	660
475	669	679	688	697	706	715	724	733	742	752
476	761	770	779	788	797	806	815	825	834	843
477	852	861	870	879	888	897	906	916	925	934
478	943	952	961	970	979	988	997	*006	*015	*024
479	68 034	043	052	061	070	079	088	097	106	115
480	124	133	142	151	160	169	178	187	196	205
481	215	224	233	242	251	260	269	278	287	296
482	305	314	323	332	341	350	359	368	377	386
483	395	404	413	422	431	440	449	458	467	476
484	485	494	502	511	520	529	538	547	556	565
485	574	583	592	601	610	619	628	637	646	655
486	664	673	681	690	699	708	717	726	735	744
487	753	762	771	780	789	797	806	815	824	833
488	842	851	860	869	878	886	895	904	913	922
489	931	940	949	958	966	975	984	993	*002	*011
490	69 020	028	037	046	055	064	073	082	090	099
491	108	117	126	135	144	152	161	170	179	188
492	197	205	214	223	232	241	249	258	267	276
493	285	294	302	311	320	329	338	346	355	364
494	373	381	390	399	408	417	425	434	443	452
495	461	469	478	487	496	504	513	522	531	539
496	548	557	566	574	583	592	601	609	618	627
497	636	644	653	662	671	679	688	697	705	714
498	723	732	740	749	758	767	775	784	793	801
499	810	819	827	836	845	854	862	871	880	888
500	897	906	914	923	932	940	949	958	966	975
N.	L. 0	1	2	3	4	5	6	7	8	9

P. P.

	10	9	8
1	1.0	0.9	0.8
2	2.0	1.8	1.6
3	3.0	2.7	2.4
4	4.0	3.6	3.2
5	5.0	4.5	4.0
6	6.0	5.4	4.8
7	7.0	6.3	5.6
8	8.0	7.2	6.4
9	9.0	8.1	7.2

Table 91 (*Continued*)
Logarithms of Numbers

N.	L. 0	1	2	3	4	5	6	7	8	9	P. P.
500	69 897	906	914	923	932	940	949	958	966	975	
501	984	992	*001	*010	*018	*027	*036	*044	*053	*062	
502	70 070	079	088	096	105	114	122	131	140	148	
503	157	165	174	183	191	200	209	217	226	234	
504	243	252	260	269	278	286	295	303	312	321	
505	329	338	346	355	364	372	381	389	398	406	
506	415	424	432	441	449	458	467	475	484	492	
507	501	509	518	526	535	544	552	561	569	578	9
508	586	595	603	612	621	629	638	646	655	663	1 0.9
509	672	680	689	697	706	714	723	731	740	749	2 1.8
510	757	766	774	783	791	800	808	817	825	834	3 2.7
511	842	851	859	868	876	885	893	902	910	919	4 3.6
512	927	935	944	952	961	969	978	986	995	*003	5 4.5
513	71 012	020	029	037	046	054	063	071	079	088	6 5.4
514	096	105	113	122	130	139	147	155	164	172	7 6.3
515	181	189	198	206	214	223	231	240	248	257	8 7.2
516	265	273	282	290	299	307	315	324	332	341	9 8.1
517	349	357	366	374	383	391	399	408	416	425	
518	433	441	450	458	466	475	483	492	500	508	
519	517	525	533	542	550	559	567	575	584	592	
520	600	609	617	625	634	642	650	659	667	675	8
521	684	692	700	709	717	725	734	742	750	759	1 0.8
522	767	775	784	792	800	809	817	825	834	842	2 1.6
523	850	858	867	875	883	892	900	908	917	925	3 2.4
524	933	941	950	958	966	975	983	991	999	*008	4 3.2
525	72 016	024	032	041	049	057	066	074	082	090	5 4.0
526	099	107	115	123	132	140	148	156	165	173	6 4.8
527	181	189	198	206	214	222	230	239	247	255	7 5.6
528	263	272	280	288	296	304	313	321	329	337	8 6.4
529	346	354	362	370	378	387	395	403	411	419	9 7.2
530	428	436	444	452	460	469	477	485	493	501	
531	509	518	526	534	542	550	558	567	575	583	
532	591	599	607	616	624	632	640	648	656	665	
533	673	681	689	697	705	713	722	730	738	746	
534	754	762	770	779	787	795	803	811	819	827	
535	835	843	852	860	868	876	884	892	900	908	
536	916	925	933	941	949	957	965	973	981	989	7
537	997	*006	*014	*022	*030	*038	*046	*054	*062	*070	1 0.7
538	73 078	086	094	102	111	119	127	135	143	151	2 1.4
539	159	167	175	183	191	199	207	215	223	231	3 2.1
540	239	247	255	263	272	280	288	296	304	312	4 2.8
541	320	328	336	344	352	360	368	376	384	392	5 3.5
542	400	408	416	424	432	440	448	456	464	472	6 4.2
543	480	488	496	504	512	520	528	536	544	552	7 4.9
544	560	568	576	584	592	600	608	616	624	632	8 5.6
545	640	648	656	664	672	679	687	695	703	711	9 6.3
546	719	727	735	743	751	759	767	775	783	791	
547	799	807	815	823	830	838	846	854	862	870	
548	878	886	894	902	910	918	926	933	941	949	
549	957	965	973	981	989	997	*005	*013	*020	*028	
550	74 036	044	052	060	068	076	084	092	099	107	
N.	**L. 0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**P. P.**

TABLE 91 (*Continued*)
LOGARITHMS OF NUMBERS

N.	L. 0	1	2	3	4	5	6	7	8	9	P. P.
550	74 036	044	052	060	068	076	084	092	099	107	
551	115	123	131	139	147	155	162	170	178	186	
552	194	202	210	218	225	233	241	249	257	265	
553	273	280	288	296	304	312	320	327	335	343	
554	351	359	367	374	382	390	398	406	414	421	
555	429	437	445	453	461	468	476	484	492	500	
556	507	515	523	531	539	547	554	562	570	578	
557	586	593	601	609	617	624	632	640	648	656	
558	663	671	679	687	695	702	710	718	726	733	
559	741	749	757	764	772	780	788	796	803	811	
560	819	827	834	842	850	858	865	873	881	889	8
561	896	904	912	920	927	935	943	950	958	966	1 0.8
562	974	981	989	997	*005	*012	*020	*028	*035	*043	2 1.6
563	75 051	059	066	074	082	089	097	105	113	120	3 2.4
564	128	136	143	151	159	166	174	182	189	197	4 3.2
565	205	213	220	228	236	243	251	259	266	274	5 4.0
566	282	289	297	305	312	320	328	335	343	351	6 4.8
567	358	366	374	381	389	397	404	412	420	427	7 5.6
568	435	442	450	458	465	473	481	488	496	504	8 6.4
569	511	519	526	534	542	549	557	565	572	580	9 7.2
570	587	595	603	610	618	626	633	641	648	656	
571	664	671	679	686	694	702	709	717	724	732	
572	740	747	755	762	770	778	785	793	800	808	
573	815	823	831	838	846	853	861	868	876	884	
574	891	899	906	914	921	929	937	944	952	959	
575	967	974	982	989	997	*005	*012	*020	*027	*035	
576	76 042	050	057	065	072	080	087	095	103	110	
577	118	125	133	140	148	155	163	170	178	185	
578	193	200	208	215	223	230	238	245	253	260	
579	268	275	283	290	298	305	313	320	328	335	
580	343	350	358	365	373	380	388	395	403	410	7
581	418	425	433	440	448	455	462	470	477	485	1 0.7
582	492	500	507	515	522	530	537	545	552	559	2 1.4
583	567	574	582	589	597	604	612	619	626	634	3 2.1
584	641	649	656	664	671	678	686	693	701	708	4 2.8
585	716	723	730	738	745	753	760	768	775	782	5 3.5
586	790	797	805	812	819	827	834	842	849	856	6 4.2
587	864	871	879	886	893	901	908	916	923	930	7 4.9
588	938	945	953	960	967	975	982	989	997	*004	8 5.6
589	77 012	019	026	034	041	048	056	063	070	078	9 6.3
590	085	093	100	107	115	122	129	137	144	151	
591	159	166	173	181	188	195	203	210	217	225	
592	232	240	247	254	262	269	276	283	291	298	
593	305	313	320	327	335	342	349	357	364	371	
594	379	386	393	401	408	415	422	430	437	444	
595	452	459	466	474	481	488	495	503	510	517	
596	525	532	539	546	554	561	568	576	583	590	
597	597	605	612	619	627	634	641	648	656	663	
598	670	677	685	692	699	706	714	721	728	735	
599	743	750	757	764	772	779	786	793	801	808	
600	815	822	830	837	844	851	859	866	873	880	
N.	L. 0	1	2	3	4	5	6	7	8	9	P. P.

Table 91 (*Continued*)
Logarithms of Numbers

N.	L. 0	1	2	3	4	5	6	7	8	9
600	77 815	822	830	837	844	851	859	866	873	880
601	887	895	902	909	916	924	931	938	945	952
602	960	967	974	981	988	996	*003	*010	*017	*025
603	78 032	039	046	053	061	068	075	082	089	097
604	104	111	118	125	132	140	147	154	161	168
605	176	183	190	197	204	211	219	226	233	240
606	247	254	262	269	276	283	290	297	305	312
607	319	326	333	340	347	355	362	369	376	383
608	390	398	405	412	419	426	433	440	447	455
609	462	469	476	483	490	497	504	512	519	526
610	533	540	547	554	561	569	576	583	590	597
611	604	611	618	625	633	640	647	654	661	668
612	675	682	689	696	704	711	718	725	732	739
613	746	753	760	767	774	781	789	796	803	810
614	817	824	831	838	845	852	859	866	873	880
615	888	895	902	909	916	923	930	937	944	951
616	958	965	972	979	986	993	*000	*007	*014	*021
617	79 029	036	043	050	057	064	071	078	085	092
618	099	106	113	120	127	134	141	148	155	162
619	169	176	183	190	197	204	211	218	225	232
620	239	246	253	260	267	274	281	288	295	302
621	309	316	323	330	337	344	351	358	365	372
622	379	386	393	400	407	414	421	428	435	442
623	449	456	463	470	477	484	491	498	505	511
624	518	525	532	539	546	553	560	567	574	581
625	588	595	602	609	616	623	630	637	644	650
626	657	664	671	678	685	692	699	706	713	720
627	727	734	741	748	754	761	768	775	782	789
628	796	803	810	817	824	831	837	844	851	858
629	865	872	879	886	893	900	906	913	920	927
630	934	941	948	955	962	969	975	982	989	996
631	80 003	010	017	024	030	037	044	051	058	065
632	072	079	085	092	099	106	113	120	127	134
633	140	147	154	161	168	175	182	188	195	202
634	209	216	223	229	236	243	250	257	264	271
635	277	284	291	298	305	312	318	325	332	339
636	346	353	359	366	373	380	387	393	400	407
637	414	421	428	434	441	448	455	462	468	475
638	482	489	496	502	509	516	523	530	536	543
639	550	557	564	570	577	584	591	598	604	611
640	618	625	632	638	645	652	659	665	672	679
641	686	693	699	706	713	720	726	733	740	747
642	754	760	767	774	781	787	794	801	808	814
643	821	828	835	841	848	855	862	868	875	882
644	889	895	902	909	916	922	929	936	943	949
645	956	963	969	976	983	990	996	*003	*010	*017
646	81 023	030	037	043	050	057	064	070	077	084
647	090	097	104	111	117	124	131	137	144	151
648	158	164	171	178	184	191	198	204	211	218
649	224	231	238	245	251	258	265	271	278	285
650	291	298	305	311	318	325	331	338	345	351
N.	L. 0	1	2	3	4	5	6	7	8	9

P. P.

	8
1	0.8
2	1.6
3	2.4
4	3.2
5	4.0
6	4.8
7	5.6
8	6.4
9	7.2

	7
1	0.7
2	1.4
3	2.1
4	2.8
5	3.5
6	4.2
7	4.9
8	5.6
9	6.3

	6
1	0.6
2	1.2
3	1.8
4	2.4
5	3.0
6	3.6
7	4.2
8	4.8
9	5.4

TABLE 91 (*Continued*)
LOGARITHMS OF NUMBERS

N.	L. 0	1	2	3	4	5	6	7	8	9	P. P.
650	81 291	298	305	311	318	325	331	338	345	351	
651	358	365	371	378	385	391	398	405	411	418	
652	425	431	438	445	451	458	465	471	478	485	
653	491	498	505	511	518	525	531	538	544	551	
654	558	564	571	578	584	591	598	604	611	617	
655	624	631	637	644	651	657	664	671	677	684	
656	690	697	704	710	717	723	730	737	743	750	
657	757	763	770	776	783	790	796	803	809	816	
658	823	829	836	842	849	856	862	869	875	882	
659	889	895	902	908	915	921	928	935	941	948	
660	954	961	968	974	981	987	994	*000	*007	*014	7
661	82 020	027	033	040	046	053	060	066	073	079	1 0.7
662	086	092	099	105	112	119	125	132	138	145	2 1.4
663	151	158	164	171	178	184	191	197	204	210	3 2.1
664	217	223	230	236	243	249	256	263	269	276	4 2.8
665	282	289	295	302	308	315	321	328	334	341	5 3.5
666	347	354	360	367	373	380	387	393	400	406	6 4.2
667	413	419	426	432	439	445	452	458	465	471	7 4.9
668	478	484	491	497	504	510	517	523	530	536	8 5.6
669	543	549	556	562	569	575	582	588	595	601	9 6.3
670	607	614	620	627	633	640	646	653	659	666	
671	672	679	685	692	698	705	711	718	724	730	
672	737	743	750	756	763	769	776	782	789	795	
673	802	808	814	821	827	834	840	847	853	860	
674	866	872	879	885	892	898	905	911	918	924	
675	930	937	943	950	956	963	969	975	982	988	
676	995	*001	*008	*014	*020	*027	*033	*040	*046	*052	
677	83 059	065	072	078	085	091	097	104	110	117	
678	123	129	136	142	149	155	161	168	174	181	
679	187	193	200	206	213	219	225	232	238	245	
680	251	257	264	270	276	283	289	296	302	308	6
681	315	321	327	334	340	347	353	359	366	372	1 0.6
682	378	385	391	398	404	410	417	423	429	436	2 1.2
683	442	448	455	461	467	474	480	487	493	499	3 1.8
684	506	512	518	525	531	537	544	550	556	563	4 2.4
685	569	575	582	588	594	601	607	613	620	626	5 3.0
686	632	639	645	651	658	664	670	677	683	689	6 3.6
687	696	702	708	715	721	727	734	740	746	753	7 4.2
688	759	765	771	778	784	790	797	803	809	816	8 4.8
689	822	828	835	841	847	853	860	866	872	879	9 5.4
690	885	891	897	904	910	916	923	929	935	942	
691	948	954	960	967	973	979	985	992	998	*004	
692	84 011	017	023	029	036	042	048	055	061	067	
693	073	080	086	092	098	105	111	117	123	130	
694	136	142	148	155	161	167	173	180	186	192	
695	198	205	211	217	223	230	236	242	248	255	
696	261	267	273	280	286	292	298	305	311	317	
697	323	330	336	342	348	354	361	367	373	379	
698	386	392	398	404	410	417	423	429	435	442	
699	448	454	460	466	473	479	485	491	497	504	
700	510	516	522	528	535	541	547	553	559	566	
N.	L. 0	1	2	3	4	5	6	7	8	9	P. P.

TABLE 91 (*Continued*)
LOGARITHMS OF NUMBERS

N.	L. 0	1	2	3	4	5	6	7	8	9
700	84 510	516	522	528	535	541	547	553	559	566
701	572	578	584	590	597	603	609	615	621	628
702	634	640	646	652	658	665	671	677	683	689
703	696	702	708	714	720	726	733	739	745	751
704	757	763	770	776	782	788	794	800	807	813
705	819	825	831	837	844	850	856	862	868	874
706	880	887	893	899	905	911	917	924	930	936
707	942	948	954	960	967	973	979	985	991	997
708	85 003	009	016	022	028	034	040	046	052	058
709	065	071	077	083	089	095	101	107	114	120
710	126	132	138	144	150	156	163	169	175	181
711	187	193	199	205	211	217	224	230	236	242
712	248	254	260	266	272	278	285	291	297	303
713	309	315	321	327	333	339	345	352	358	364
714	370	376	382	388	394	400	406	412	418	425
715	431	437	443	449	455	461	467	473	479	485
716	491	497	503	509	516	522	528	534	540	546
717	552	558	564	570	576	582	588	594	600	606
718	612	618	625	631	637	643	649	655	661	667
719	673	679	685	691	697	703	709	715	721	727
720	733	739	745	751	757	763	769	775	781	788
721	794	800	806	812	818	824	830	836	842	848
722	854	860	866	872	878	884	890	896	902	908
723	914	920	926	932	938	944	950	956	962	968
724	974	980	986	992	998	*004	*010	*016	*022	*028
725	86 034	040	046	052	058	064	070	076	082	088
726	094	100	106	112	118	124	130	136	141	147
727	153	159	165	171	177	183	189	195	201	207
728	213	219	225	231	237	243	249	255	261	267
729	273	279	285	291	297	303	308	314	320	326
730	332	338	344	350	356	362	368	374	380	386
731	392	398	404	410	415	421	427	433	439	445
732	451	457	463	469	475	481	487	493	499	504
733	510	516	522	528	534	540	546	552	558	564
734	570	576	581	587	593	599	605	611	617	623
735	629	635	641	646	652	658	664	670	676	682
736	688	694	700	705	711	717	723	729	735	741
737	747	753	759	764	770	776	782	788	794	800
738	806	812	817	823	829	835	841	847	853	859
739	864	870	876	882	888	894	900	906	911	917
740	923	929	935	941	947	953	958	964	970	976
741	982	988	994	999	*005	*011	*017	*023	*029	*035
742	87 040	046	052	058	064	070	075	081	087	093
743	099	105	111	116	122	128	134	140	146	151
744	157	163	169	175	181	186	192	198	204	210
745	216	221	227	233	239	245	251	256	262	268
746	274	280	286	291	297	303	309	315	320	326
747	332	338	344	349	355	361	367	373	379	384
748	390	396	402	408	413	419	425	431	437	442
749	448	454	460	466	471	477	483	489	495	500
750	506	512	518	523	529	535	541	547	552	558
N.	L. 0	1	2	3	4	5	6	7	8	9

P. P.

	7
1	0.7
2	1.4
3	2.1
4	2.8
5	3.5
6	4.2
7	4.9
8	5.6
9	6.3

	6
1	0.6
2	1.2
3	1.8
4	2.4
5	3.0
6	3.6
7	4.2
8	4.8
9	5.4

	5
1	0.5
2	1.0
3	1.5
4	2.0
5	2.5
6	3.0
7	3.5
8	4.0
9	4.5

Table 91 (*Continued*)
Logarithms of Numbers

N.	L. 0	1	2	3	4	5	6	7	8	9	P. P.
750	87 506	512	518	523	529	535	541	547	552	558	
751	564	570	576	581	587	593	599	604	610	616	
752	622	628	633	639	645	651	656	662	668	674	
753	679	685	691	697	703	708	714	720	726	731	
754	737	743	749	754	760	766	772	777	783	789	
755	795	800	806	812	818	823	829	835	841	846	
756	852	858	864	869	875	881	887	892	898	904	
757	910	915	921	927	933	938	944	950	955	961	
758	967	973	978	984	990	996	*001	*007	*013	*018	
759	88 024	030	036	041	047	053	058	064	070	076	
760	081	087	093	098	104	110	116	121	127	133	
761	138	144	150	156	161	167	173	178	184	190	6
762	195	201	207	213	218	224	230	235	241	247	1 0.6
763	252	258	264	270	275	281	287	292	298	304	2 1.2
764	309	315	321	326	332	338	343	349	355	360	3 1.8
765	366	372	377	383	389	395	400	406	412	417	4 2.4
766	423	429	434	440	446	451	457	463	468	474	5 3.0
767	480	485	491	497	502	508	513	519	525	530	6 3.6
768	536	542	547	553	559	564	570	576	581	587	7 4.2 8 4.8
769	593	598	604	610	615	621	627	632	638	643	9 5.4
770	649	655	660	666	672	677	683	689	694	700	
771	705	711	717	722	728	734	739	745	750	756	
772	762	767	773	779	784	790	795	801	807	812	
773	818	824	829	835	840	846	852	857	863	868	
774	874	880	885	891	897	902	908	913	919	925	
775	930	936	941	947	953	958	964	969	975	981	
776	986	992	997	*003	*009	*014	*020	*025	*031	*037	
777	89 042	048	053	059	064	070	076	081	087	092	
778	098	104	109	115	120	126	131	137	143	148	
779	154	159	165	170	176	182	187	193	198	204	
780	209	215	221	226	232	237	243	248	254	260	
781	265	271	276	282	287	293	298	304	310	315	5
782	321	326	332	337	343	348	354	360	365	371	1 0.5
783	376	382	387	393	398	404	409	415	421	426	2 1.0
784	432	437	443	448	454	459	465	470	476	481	3 1.5
785	487	492	498	504	509	515	520	526	531	537	4 2.0
786	542	548	553	559	564	570	575	581	586	592	5 2.5
787	597	603	609	614	620	625	631	636	642	647	6 3.0
788	653	658	664	669	675	680	686	691	697	702	7 3.5 8 4.0
789	708	713	719	724	730	735	741	746	752	757	9 4.5
790	763	768	774	779	785	790	796	801	807	812	
791	818	823	829	834	840	845	851	856	862	867	
792	873	878	883	889	894	900	905	911	916	922	
793	927	933	938	944	949	955	960	966	971	977	
794	982	988	993	998	*004	*009	*015	*020	*026	*031	
795	90 037	042	048	053	059	064	069	075	080	086	
796	091	097	102	108	113	119	124	129	135	140	
797	146	151	157	162	168	173	179	184	189	195	
798	200	206	211	217	222	227	233	238	244	249	
799	255	260	266	271	276	282	287	293	298	304	
800	309	314	320	325	331	336	342	347	352	358	
N.	L. 0	1	2	3	4	5	6	7	8	9	P. P.

Table 91 (*Continued*)
Logarithms of Numbers

N.	L. 0	1	2	3	4	5	6	7	8	9	P. P.
800	90 309	314	320	325	331	336	342	347	352	358	
801	363	369	374	380	385	390	396	401	407	412	
802	417	423	428	434	439	445	450	455	461	466	
803	472	477	482	488	493	499	504	509	515	520	
804	526	531	536	542	547	553	558	563	569	574	
805	580	585	590	596	601	607	612	617	623	628	
806	634	639	644	650	655	660	666	671	677	682	
807	687	693	698	703	709	714	720	725	730	736	
808	741	747	752	757	763	768	773	779	784	789	
809	795	800	806	811	816	822	827	832	838	843	
810	849	854	859	865	870	875	881	886	891	897	6
811	902	907	913	918	924	929	934	940	945	950	1 0.6
812	956	961	966	972	977	982	988	993	998	*004	2 1.2
813	91 009	014	020	025	030	036	041	046	052	057	3 1.8
814	062	068	073	078	084	089	094	100	105	110	4 2.4
815	116	121	126	132	137	142	148	153	158	164	5 3.0
816	169	174	180	185	190	196	201	206	212	217	6 3.6
817	222	228	233	238	243	249	254	259	265	270	7 4.2
818	275	281	286	291	297	302	307	312	318	323	8 4.8
819	328	334	339	344	350	355	360	365	371	376	9 5.4
820	381	387	392	397	403	408	413	418	424	429	
821	434	440	445	450	455	461	466	471	477	482	
822	487	492	498	503	508	514	519	524	529	535	
823	540	545	551	556	561	566	572	577	582	587	
824	593	598	603	609	614	619	624	630	635	640	
825	645	651	656	661	666	672	677	682	687	693	
826	698	703	709	714	719	724	730	735	740	745	
827	751	756	761	766	772	777	782	787	793	798	
828	803	808	814	819	824	829	834	840	845	850	
829	855	861	866	871	876	882	887	892	897	903	
830	908	913	918	924	929	934	939	944	950	955	5
831	960	965	971	976	981	986	991	997	*002	*007	1 0.5
832	92 012	018	023	028	033	038	044	049	054	059	2 1.0
833	065	070	075	080	085	091	096	101	106	111	3 1.5
834	117	122	127	132	137	143	148	153	158	163	4 2.0
835	169	174	179	184	189	195	200	205	210	215	5 2.5
836	221	226	231	236	241	247	252	257	262	267	6 3.0
837	273	278	283	288	293	298	304	309	314	319	7 3.5
838	324	330	335	340	345	350	355	361	366	371	8 4.0
839	376	381	387	392	397	402	407	412	418	423	9 4.5
840	428	433	438	443	449	454	459	464	469	474	
841	480	485	490	495	500	505	511	516	521	526	
842	531	536	542	547	552	557	562	567	572	578	
843	583	588	593	598	603	609	614	619	624	629	
844	634	639	645	650	655	660	665	670	675	681	
845	686	691	696	701	706	711	716	722	727	732	
846	737	742	747	752	758	763	768	773	778	783	
847	788	793	799	804	809	814	819	824	829	834	
848	840	845	850	855	860	865	870	875	881	886	
849	891	896	901	906	911	916	921	927	932	937	
850	942	947	952	957	962	967	973	978	983	988	
N.	**L. 0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**P. P.**

TABLE 91 (*Continued*)
LOGARITHMS OF NUMBERS

N.	L. 0	1	2	3	4	5	6	7	8	9	P.P.
850	92 942	947	952	957	962	967	973	978	983	988	
851	993	998	*003	*008	*013	*018	*024	*029	*034	*039	
852	93 044	049	054	059	064	069	075	080	085	090	
853	095	100	105	110	115	120	125	131	136	141	
854	146	151	156	161	166	171	176	181	186	192	
855	197	202	207	212	217	222	227	232	237	242	
856	247	252	258	263	268	273	278	283	288	293	
857	298	303	308	313	318	323	328	334	339	344	
858	349	354	359	364	369	374	379	384	389	394	
859	399	404	409	414	420	425	430	435	440	445	
860	450	455	460	465	470	475	480	485	490	495	
861	500	505	510	515	520	526	531	536	541	546	
862	551	556	561	566	571	576	581	586	591	596	
863	601	606	611	616	621	626	631	636	641	646	
864	651	656	661	666	671	676	682	687	692	697	
865	702	707	712	717	722	727	732	737	742	747	
866	752	757	762	767	772	777	782	787	792	797	
867	802	807	812	817	822	827	832	837	842	847	
868	852	857	862	867	872	877	882	887	892	897	
869	902	907	912	917	922	927	932	937	942	947	
870	952	957	962	967	972	977	982	987	992	997	
871	94 002	007	012	017	022	027	032	037	042	047	
872	052	057	062	067	072	077	082	086	091	096	
873	101	106	111	116	121	126	131	136	141	146	
874	151	156	161	166	171	176	181	186	191	196	
875	201	206	211	216	221	226	231	236	240	245	
876	250	255	260	265	270	275	280	285	290	295	
877	300	305	310	315	320	325	330	335	340	345	
878	349	354	359	364	369	374	379	384	389	394	
879	399	404	409	414	419	424	429	433	438	443	
880	448	453	458	463	468	473	478	483	488	493	
881	498	503	507	512	517	522	527	532	537	542	
882	547	552	557	562	567	571	576	581	586	591	
883	596	601	606	611	616	621	626	630	635	640	
884	645	650	655	660	665	670	675	680	685	689	
885	694	699	704	709	714	719	724	729	734	738	
886	743	748	753	758	763	768	773	778	783	787	
887	792	797	802	807	812	817	822	827	832	836	
888	841	846	851	856	861	866	871	876	880	885	
889	890	895	900	905	910	915	919	924	929	934	
890	939	944	949	954	959	963	968	973	978	983	
891	988	993	998	*002	*007	*012	*017	*022	*027	*032	
892	95 036	041	046	051	056	061	066	071	075	080	
893	085	090	095	100	105	109	114	119	124	129	
894	134	139	143	148	153	158	163	168	173	177	
895	182	187	192	197	202	207	211	216	221	226	
896	231	236	240	245	250	255	260	265	270	274	
897	279	284	289	294	299	303	308	313	318	323	
898	328	332	337	342	347	352	357	361	366	371	
899	376	381	386	390	395	400	405	410	415	419	
900	424	429	434	439	444	448	453	458	463	468	
N.	L. 0	1	2	3	4	5	6	7	8	9	P.P.

P.P.

	6
1	0.6
2	1.2
3	1.8
4	2.4
5	3.0
6	3.6
7	4.2
8	4.8
9	5.4

	5
1	0.5
2	1.0
3	1.5
4	2.0
5	2.5
6	3.0
7	3.5
8	4.0
9	4.5

	4
1	0.4
2	0.8
3	1.2
4	1.6
5	2.0
6	2.4
7	2.8
8	3.2
9	3.6

TABLE 91 (*Continued*)
LOGARITHMS OF NUMBERS

N.	L. 0	1	2	3	4	5	6	7	8	9	P. P.
900	95 424	429	434	439	444	448	453	458	463	468	
901	472	477	482	487	492	497	501	506	511	516	
902	521	525	530	535	540	545	550	554	559	564	
903	569	574	578	583	588	593	598	602	607	612	
904	617	622	626	631	636	641	646	650	655	660	
905	665	670	674	679	684	689	694	698	703	708	
906	713	718	722	727	732	737	742	746	751	756	
907	761	766	770	775	780	785	789	794	799	804	
908	809	813	818	823	828	832	837	842	847	852	
909	856	861	866	871	875	880	885	890	895	899	
910	904	909	914	918	923	928	933	938	942	947	5
911	952	957	961	966	971	976	980	985	990	995	1 0.5
912	999	*004	*009	*014	*019	*023	*028	*033	*038	*042	2 1.0
913	96 047	052	057	061	066	071	076	080	085	090	3 1.5
914	095	099	104	109	114	118	123	128	133	137	4 2.0
915	142	147	152	156	161	166	171	175	180	185	5 2.5
916	190	194	199	204	209	213	218	223	227	232	6 3.0
917	237	242	246	251	256	261	265	270	275	280	7 3.5
918	284	289	294	298	303	308	313	317	322	327	8 4.0
919	332	336	341	346	350	355	360	365	369	374	9 4.5
920	379	384	388	393	398	402	407	412	417	421	
921	426	431	435	440	445	450	454	459	464	468	
922	473	478	483	487	492	497	501	506	511	515	
923	520	525	530	534	539	544	548	553	558	562	
924	567	572	577	581	586	591	595	600	605	609	
925	614	619	624	628	633	638	642	647	652	656	
926	661	666	670	675	680	685	689	694	699	703	
927	708	713	717	722	727	731	736	741	745	750	
928	755	759	764	769	774	778	783	788	792	797	
929	802	806	811	816	820	825	830	834	839	844	
930	848	853	858	862	867	872	876	881	886	890	4
931	895	900	904	909	914	918	923	928	932	937	1 0.4
932	942	946	951	956	960	965	970	974	979	984	2 0.8
933	988	993	997	*002	*007	*011	*016	*021	*025	*030	3 1.2
934	97 035	039	044	049	053	058	063	067	072	077	4 1.6
935	081	086	090	095	100	104	109	114	118	123	5 2.0
936	128	132	137	142	146	151	155	160	165	169	6 2.4
937	174	179	183	188	192	197	202	206	211	216	7 2.8
938	220	225	230	234	239	243	248	253	257	262	8 3.2
939	267	271	276	280	285	290	294	299	304	308	9 3.6
940	313	317	322	327	331	336	340	345	350	354	
941	359	364	368	373	377	382	387	391	396	400	
942	405	410	414	419	424	428	433	437	442	447	
943	451	456	460	465	470	474	479	483	488	493	
944	497	502	506	511	516	520	525	529	534	539	
945	543	548	552	557	562	566	571	575	580	585	
946	589	594	598	603	607	612	617	621	626	630	
947	635	640	644	649	653	658	663	667	672	676	
948	681	685	690	695	699	704	708	713	717	722	
949	727	731	736	740	745	749	754	759	763	768	
950	772	777	782	786	791	795	800	804	809	813	
N.	L. 0	1	2	3	4	5	6	7	8	9	P. P.

TABLE 91 (*Concluded*)
LOGARITHMS OF NUMBERS

N.	L. 0	1	2	3	4	5	6	7	8	9	P. P.	
950	97 772	777	782	786	791	795	800	804	809	813		
951	818	823	827	832	836	841	845	850	855	859		
952	864	868	873	877	882	886	891	896	900	905		
953	909	914	918	923	928	932	937	941	946	950		
954	955	959	964	968	973	978	982	987	991	996		
955	98 000	005	009	014	019	023	028	032	037	041		
956	046	050	055	059	064	068	073	078	082	087		
957	091	096	100	105	109	114	118	123	127	132		
958	137	141	146	150	155	159	164	168	173	177		
959	182	186	191	195	200	204	209	214	218	223		
960	227	232	236	241	245	250	254	259	263	268		5
961	272	277	281	286	290	295	299	304	308	313	1	0.5
962	318	322	327	331	336	340	345	349	354	358	2	1.0
963	363	367	372	376	381	385	390	394	399	403	3	1.5
964	408	412	417	421	426	430	435	439	444	448	4	2.0
965	453	457	462	466	471	475	480	484	489	493	5	2.5
966	498	502	507	511	516	520	525	529	534	538	6	3.0
967	543	547	552	556	561	565	570	574	579	583	7	3.5
968	588	592	597	601	605	610	614	619	623	628	8	4.0
969	632	637	641	646	650	655	659	664	668	673	9	4.5
970	677	682	686	691	695	700	704	709	713	717		
971	722	726	731	735	740	744	749	753	758	762		
972	767	771	776	780	784	789	793	798	802	807		
973	811	816	820	825	829	834	838	843	847	851		
974	856	860	865	869	874	878	883	887	892	896		
975	900	905	909	914	918	923	927	932	936	941		
976	945	949	954	958	963	967	972	976	981	985		
977	989	994	998	*003	*007	*012	*016	*021	*025	*029		
978	99 034	038	043	047	052	056	061	065	069	074		
979	078	083	087	092	096	100	105	109	114	118		
980	123	127	131	136	140	145	149	154	158	162		4
981	167	171	176	180	185	189	193	198	202	207	1	0.4
982	211	216	220	224	229	233	238	242	247	251	2	0.8
983	255	260	264	269	273	277	282	286	291	295	3	1.2
984	300	304	308	313	317	322	326	330	335	339	4	1.6
985	344	348	352	357	361	366	370	374	379	383	5	2.0
986	388	392	396	401	405	410	414	419	423	427	6	2.4
987	432	436	441	445	449	454	458	463	467	471	7	2.8
988	476	480	484	489	493	498	502	506	511	515	8	3.2
989	520	524	528	533	537	542	546	550	555	559	9	3.6
990	564	568	572	577	581	585	590	594	599	603		
991	607	612	616	621	625	629	634	638	642	647		
992	651	656	660	664	669	673	677	682	686	691		
993	695	699	704	708	712	717	721	726	730	734		
994	739	743	747	752	756	760	765	769	774	778		
995	782	787	791	795	800	804	808	813	817	822		
996	826	830	835	839	843	848	852	856	861	865		
997	870	874	878	883	887	891	896	900	904	909		
998	913	917	922	926	930	935	939	944	948	952		
999	957	961	965	970	974	978	983	987	991	996		
1000	00 000	004	009	013	017	022	026	030	035	039		
N.	L. 0	1	2	3	4	5	6	7	8	9	P. P.	

Table 92.—Cologarithms of Numbers

No.	0	1	2	3	4	5	6	7	8	9	P.P.			
100	.00 000	*957	*913	*870	*827	*783	*740	*697	*654	*611		**44**	**43**	**42**
1	.99 568	525	482	439	396	353	311	268	225	183	1	4	4	4
2	140	097	055	012	*970	*928	*885	*843	*801	*758	2	9	9	8
3	.98 716	674	632	590	548	506	464	422	380	338	3	13	13	13
4	297	255	213	172	130	088	047	005	*964	*922	4	18	17	17
5	.97 881	840	798	757	716	675	634	593	551	510	5	22	22	21
6	469	428	388	347	306	265	224	184	143	102	6	26	26	25
7	062	021	*981	*940	*900	*859	*819	*778	*738	*698	7	31	30	29
8	.96 658	617	577	537	497	457	417	377	337	297	8	35	34	34
9	257	218	178	138	098	059	019	*979	*940	*900	9	40	39	38
110	.95 861	821	782	742	703	664	624	585	546	507		**41**	**40**	**39**
1	468	429	390	350	311	273	234	195	156	117	1	4	4	4
2	078	039	001	*962	*923	*885	*846	*808	*769	*731	2	8	8	8
3	.94 692	654	615	577	539	500	462	424	386	348	3	12	12	12
4	310	271	233	195	157	119	082	044	006	*968	4	16	16	16
5	.93 930	892	855	817	779	742	704	667	629	592	5	21	20	20
6	554	517	479	442	405	367	330	293	256	219	6	25	24	23
7	181	144	107	070	033	*996	*959	*922	*885	*849	7	29	28	27
8	.92 812	775	738	702	665	628	592	555	518	482	8	33	32	31
9	445	409	372	336	300	263	227	191	154	118	9	37	36	35
120	082	046	010	*973	*937	*901	*865	*829	*793	*757		**38**	**37**	**36**
1	.91 721	686	650	614	578	542	507	471	435	400	1	4	4	4
2	364	328	293	257	222	186	151	116	080	045	2	8	7	7
3	009	*974	*939	*904	*868	*833	*798	*763	*728	*693	3	11	11	11
4	.90 658	623	588	553	518	483	448	413	379	344	4	15	15	14
5	309	274	240	205	170	136	101	066	032	*997	5	19	19	18
6	.89 963	928	894	860	825	791	757	722	688	654	6	23	22	22
7	620	585	551	517	483	449	415	381	347	313	7	27	26	25
8	279	245	211	177	143	110	076	042	008	*975	8	30	30	29
9	.88 941	907	874	840	807	773	739	706	673	639	9	34	33	32
130	606	572	539	506	472	439	406	372	339	306		**35**	**34**	**33**
1	273	240	207	174	140	107	074	041	008	*976	1	4	3	3
2	.87 943	910	877	844	811	778	746	713	680	648	2	7	7	7
3	615	582	550	517	484	452	419	387	354	322	3	11	10	10
4	290	257	225	192	160	128	095	063	031	*999	4	14	14	13
5	.86 967	934	902	870	838	806	774	742	710	678	5	18	17	17
6	646	614	582	550	519	487	455	423	391	360	6	21	20	20
7	328	296	265	233	201	170	138	107	075	044	7	25	24	23
8	012	*981	*949	*918	*886	*855	*824	*792	*761	*730	8	28	27	26
9	.85 699	667	636	605	574	543	511	480	449	418	9	32	31	30
140	387	356	325	294	263	232	201	171	140	109		**32**	**31**	**30**
1	078	047	017	*986	*955	*924	*894	*863	*832	*802	1	3	3	3
2	.84 771	741	710	680	649	619	588	558	527	497	2	6	6	6
3	466	436	406	375	345	315	285	254	224	194	3	10	9	9
4	164	134	103	073	043	013	*983	*953	*923	*893	4	13	12	12
5	.83 863	833	803	773	744	714	684	654	624	594	5	16	16	15
6	565	535	505	476	446	416	387	357	327	298	6	19	19	18
7	268	239	209	180	150	121	091	062	033	003	7	22	22	21
8	.82 974	944	915	886	857	827	798	769	740	711	8	26	25	24
9	681	652	623	594	565	536	507	478	449	420	9	29	28	27
150	391	362	333	304	275	246	218	189	160	131				

Table 92 (*Continued*)

Cologarithms of Numbers

No.	0	1	2	3	4	5	6	7	8	9	P.P.		
150	.82 391	362	333	304	275	246	218	189	160	131		**29**	**28**
1	102	074	045	016	*987	*959	*930	*901	*873	*844	1	3	3
2	.81 816	787	759	730	702	673	645	616	588	559	2	6	6
3	531	502	474	446	417	389	361	333	304	276	3	9	8
4	248	220	192	163	135	107	079	051	023	*995	4	12	11
5	.80 967	939	911	883	855	827	799	771	743	715	5	15	14
6	688	660	632	604	576	549	521	493	465	438	6	17	17
7	410	382	355	327	300	272	244	217	189	162	7	20	20
8	134	107	079	052	024	*997	*970	*942	*915	*888	8	23	22
9	.79 860	833	806	778	751	724	697	670	642	615	9	26	25
160	588	561	534	507	480	452	425	398	371	344		**27**	**26**
1	317	290	263	237	210	183	156	129	102	075	1	3	3
2	048	022	*995	*968	*941	*915	*888	*861	*835	*808	2	5	5
3	.78 781	755	728	701	675	648	622	595	569	542	3	8	8
4	516	489	463	436	410	383	357	331	304	278	4	11	10
5	252	225	199	173	146	120	094	068	042	015	5	14	13
6	.77 989	963	937	911	885	859	833	806	780	754	6	16	16
7	728	702	676	650	624	599	573	547	521	495	7	19	18
8	469	443	417	392	366	340	314	288	263	237	8	22	21
9	211	186	160	134	109	083	057	032	006	*981	9	24	23
170	.76 955	930	904	879	853	828	802	777	751	726			**25**
1	700	675	650	624	599	574	548	523	498	472		1	3
2	447	422	397	371	346	321	296	271	246	221		2	5
3	195	170	145	120	095	070	045	020	*995	*970		3	8
4	.75 945	920	895	870	845	820	796	771	746	721		4	10
5	696	671	647	622	597	572	548	523	498	473		5	13
6	449	424	399	375	350	326	301	276	252	227		6	15
7	203	178	154	129	105	080	056	031	007	*982		7	18
8	.74 958	934	909	885	861	836	812	788	763	739		8	20
9	715	690	666	642	618	594	569	545	521	497		9	23
180	473	449	425	400	376	352	328	304	280	256		**24**	**23**
1	232	208	184	160	136	112	088	065	041	017	1	2	2
2	.73 993	969	945	921	898	874	850	826	802	779	2	5	5
3	755	731	707	684	660	636	613	589	565	542	3	7	7
4	518	495	471	447	424	400	377	353	330	306	4	10	9
5	283	259	236	212	189	166	142	119	095	072	5	12	12
6	049	025	002	*979	*955	*932	*909	*886	*862	*839	6	14	14
7	.72 816	793	769	746	723	700	677	654	630	607	7	17	16
8	584	561	538	515	492	469	446	423	400	377	8	19	18
9	354	331	308	285	262	239	216	193	170	148	9	22	21
190	125	102	079	056	033	011	*988	*965	*942	*919		**22**	**21**
1	.71 897	874	851	829	806	783	760	738	715	693	1	2	2
2	670	647	625	602	579	557	534	512	489	467	2	4	4
3	444	422	399	377	354	332	309	287	265	242	3	7	6
4	220	197	175	153	130	108	086	063	041	019	4	9	8
5	.70 997	974	952	930	908	885	863	841	819	797	5	11	11
6	774	752	730	708	686	664	642	620	597	575	6	13	13
7	553	531	509	487	465	443	421	399	377	355	7	15	15
8	333	312	290	268	246	224	202	180	158	137	8	18	17
9	115	093	071	049	027	006	*984	*962	*940	*919	9	20	19
200	.69 897	875	854	832	810	789	767	745	724	702			

TABLE 92 (*Continued*)

COLOGARITHMS OF NUMBERS

No.	0	1	2	3	4	5	6	7	8	9	P.P.
200	.69 897	875	854	832	810	789	767	745	724	702	**22 21**
1	680	659	637	616	594	572	551	529	508	486	1 2 2
2	465	443	422	400	379	357	336	315	293	272	2 4 4
3	250	229	208	186	165	144	122	101	080	058	3 7 6
4	037	016	*994	*973	*952	*931	*909	*888	*867	*846	4 9 8
5	.68 825	803	782	761	740	719	698	677	655	634	5 11 11
6	613	592	571	550	529	508	487	466	445	424	6 13 13
7	403	382	361	340	319	298	277	256	235	215	9 15 15
8	194	173	152	131	110	089	069	048	027	006	8 18 17
9	.67 985	965	944	923	902	882	861	840	819	799	9 20 19
210	778	757	737	716	695	675	654	634	613	592	**20**
1	572	551	531	510	490	469	448	428	407	387	1 2
2	366	346	325	305	285	264	244	223	203	182	2 4
3	162	142	121	101	081	060	040	020	*999	*979	3 6
4	.66 959	938	918	898	878	857	837	817	797	776	4 8
5	756	736	716	696	675	655	635	615	595	575	5 10
6	555	535	514	494	474	454	434	414	394	374	6 12
7	354	334	314	294	274	254	234	214	194	174	7 14
8	154	134	115	095	075	055	035	015	*995	*975	8 16
9	.65 956	936	916	896	876	857	837	817	797	777	9 18
220	758	738	718	699	679	659	639	620	600	580	**19**
1	561	541	521	502	482	463	443	423	404	384	1 2
2	365	345	326	306	287	267	247	228	208	189	2 4
3	170	150	131	111	092	072	053	033	014	*995	3 6
4	.64 975	956	936	917	898	878	859	840	820	801	4 8
5	782	762	743	724	705	685	666	647	628	608	5 10
6	589	570	551	532	512	493	474	455	436	417	6 11
7	397	378	359	340	321	302	283	264	245	226	7 13
8	207	187	168	149	130	111	092	073	054	035	8 15
9	016	*997	*979	*960	*941	*922	*903	*884	*865	*846	9 17
230	.63 827	808	789	771	752	733	714	695	676	658	**18**
1	639	620	601	582	564	545	526	507	489	470	1 2
2	451	432	414	395	376	358	339	320	302	283	2 4
3	264	246	227	209	190	171	153	134	116	097	3 5
4	078	060	041	023	004	*986	*967	*949	*930	*912	4 7
5	.62 893	875	856	838	819	801	782	764	746	727	5 9
6	709	690	672	654	635	617	599	580	562	543	6 11
7	525	507	489	470	452	434	415	397	379	361	7 13
8	342	324	306	288	269	251	233	215	197	178	8 14
9	160	142	124	106	088	069	051	033	015	*997	9 16
240	.61 979	961	943	925	907	888	870	852	834	816	**17**
1	798	780	762	744	726	708	690	672	654	636	1 2
2	618	601	583	565	547	529	511	493	475	457	2 3
3	439	422	404	386	368	350	332	314	297	279	3 5
4	261	243	225	208	190	172	154	137	119	101	4 7
5	083	066	048	030	013	*995	*977	*959	*942	*924	5 9
6	.60 906	889	871	854	836	818	801	783	765	748	6 10
7	730	713	695	678	660	642	625	607	590	572	7 12
8	555	537	520	502	485	467	450	432	415	398	8 14
9	380	363	345	328	310	293	276	258	241	223	9 15
250	206	189	171	154	137	119	102	085	067	050	

Table 92 (*Continued*)

Cologarithms of Numbers

No.	0	1	2	3	4	5	6	7	8	9	P.P.	
250	.60 206	189	171	154	137	119	102	085	067	050		18
1	033	015	*998	*981	*963	*946	*929	*912	*894	*877	1	2
2	.59 860	843	825	808	791	774	757	739	722	705	2	4
3	688	671	654	636	619	602	585	568	551	534	3	5
4	517	500	482	465	448	431	414	397	380	363	4	7
5	346	329	312	295	278	261	244	227	210	193	5	9
6	176	159	142	125	108	091	074	057	040	024	6	11
7	007	*990	*973	*956	*939	*922	*905	*889	*872	*855	7	13
8	.58 838	821	804	788	771	754	737	720	704	687	8	14
9	670	653	637	620	603	586	570	553	536	519	9	16
260	503	486	469	453	436	419	403	386	369	353		17
1	336	319	303	286	269	253	236	220	203	186	1	2
2	170	153	137	120	104	087	071	054	037	021	2	3
3	004	*988	*971	*955	*938	*922	*905	*889	*873	*856	3	5
4	.57 840	823	807	790	774	757	741	725	708	692	4	7
5	675	659	643	626	610	594	577	561	545	528	5	9
6	512	496	479	463	447	430	414	398	381	365	6	10
7	349	333	316	300	284	268	251	235	219	203	7	12
8	187	170	154	138	122	106	089	073	057	041	8	14
9	025	009	*992	*976	*960	*944	*928	*912	*896	*880	9	15
270	.56 864	848	831	815	799	783	767	751	735	719		16
1	703	687	671	655	639	623	607	591	575	559	2	2
2	543	527	511	495	479	463	447	431	416	400	2	3
3	384	368	352	336	320	304	288	273	257	241	3	5
4	225	209	193	177	162	146	130	114	098	083	4	6
5	067	051	035	019	004	988	*972	*956	*941	*925	5	8
6	.55 900	893	878	862	846	830	815	799	783	768	6	10
7	752	736	721	705	689	674	658	642	627	611	7	11
8	596	580	564	549	533	517	502	486	471	455	8	13
9	440	424	408	393	377	362	346	331	315	300	9	14
280	284	269	253	238	222	207	191	176	160	145		15
1	129	114	098	083	068	052	037	021	006	*990	1	2
2	.54 975	960	944	929	914	898	883	867	852	837	2	3
3	821	806	791	775	760	745	729	714	699	683	3	5
4	668	653	638	622	607	592	577	561	546	531	4	6
5	516	500	485	470	455	439	424	409	394	379	5	8
6	363	348	333	318	303	288	272	257	242	227	6	9
7	212	197	182	166	151	136	121	106	091	076	7	11
8	061	046	031	016	000	*985	*970	*955	*940	*925	8	12
9	.53 910	895	880	865	850	835	820	805	790	775	9	14
290	760	745	730	715	700	685	670	655	641	626		14
1	611	596	581	566	551	536	521	506	491	477	1	1
2	462	447	432	417	402	387	373	358	343	328	2	3
3	313	298	284	269	254	239	224	210	195	180	3	4
4	165	150	136	121	106	091	077	062	047	033	4	6
5	018	003	*988	*974	*959	*944	*930	*915	*900	*886	5	7
6	.52 871	856	841	827	812	798	783	768	754	739	6	8
7	724	710	695	681	666	651	637	622	608	593	7	10
8	578	564	549	535	520	506	491	476	462	447	8	11
9	433	418	404	389	375	360	346	331	317	302	9	13
300	288	273	259	244	230	216	201	187	172	158		

Table 92 (*Continued*)

Cologarithms of Numbers

No.	0	1	2	3	4	5	6	7	8	9	P.P.	
300	.52 288	273	259	244	230	216	201	187	172	158		15
1	143	129	115	100	086	071	057	042	028	014	1	2
2	.51 999	985	971	956	942	927	913	899	884	870	2	3
3	856	841	827	813	798	784	770	756	741	727	3	5
4	713	698	684	670	656	641	627	613	599	584	4	6
5	570	556	542	527	513	499	485	470	456	442	5	8
6	428	414	399	385	371	357	343	329	314	300	6	9
7	286	272	258	244	230	215	201	187	173	159	7	11
8	145	131	117	103	089	074	060	046	032	018	8	12
9	004	*990	*976	*962	*948	*934	*920	*906	*892	*878	9	14
310	.50 864	850	836	822	808	794	780	766	752	738		14
1	724	710	696	682	668	654	640	626	612	598	1	1
2	585	571	557	543	529	515	501	487	473	459	2	3
3	446	432	418	404	390	376	362	349	335	321	3	4
4	307	293	279	266	252	238	224	210	197	183	4	6
5	169	155	141	128	114	100	086	073	059	045	5	7
6	031	018	004	*990	*976	*963	*949	*935	*921	*908	6	8
7	.49 894	880	867	853	839	826	812	798	785	771	7	10
8	757	744	730	716	703	689	675	662	648	635	8	11
9	621	607	594	580	567	553	539	526	512	499	9	13
320	485	471	458	444	431	417	404	390	377	363		13
1	349	336	322	309	295	282	268	255	241	228	1	1
2	214	201	187	174	160	147	134	120	107	093	2	3
3	080	066	053	039	026	013	*999	*986	*972	*959	3	4
4	.48 945	932	919	905	892	879	865	852	838	825	4	5
5	812	798	785	772	758	745	732	718	705	692	5	7
6	678	665	652	638	625	612	598	585	572	559	6	8
7	545	532	519	505	492	479	466	452	439	426	7	9
8	413	399	386	373	360	346	333	320	307	294	8	10
9	280	267	254	241	228	214	201	188	175	162	9	12
330	149	135	122	109	096	083	070	057	043	030		12
1	017	004	*991	*978	*965	*952	*939	*925	*912	*899	1	1
2	.47 886	873	860	847	834	821	808	795	782	769	2	2
3	756	743	730	716	703	690	677	664	651	638	3	4
4	625	612	599	586	573	560	547	534	521	508	4	5
5	496	483	470	457	444	431	418	405	392	379	5	6
6	366	353	340	327	314	301	289	276	263	250	6	7
7	237	224	211	198	185	173	160	147	134	121	7	8
8	108	095	083	070	057	044	031	018	006	*993	8	10
9	.46 980	967	954	942	929	916	903	890	878	865	9	11
340	852	839	827	814	801	788	776	763	750	737		
1	725	712	699	686	674	661	648	636	623	610		
2	597	585	572	559	547	534	521	509	496	483		
3	471	458	445	433	420	407	395	382	369	357		
4	344	332	319	306	294	231	268	256	243	231		
5	218	206	193	180	168	155	143	130	118	105		
6	092	080	067	055	042	030	017	005	*992	*980		
7	.45 967	955	942	930	917	905	892	880	867	855		
8	842	830	817	805	792	780	767	755	742	730		
9	717	705	693	680	668	655	643	630	618	606		
350	593	581	568	556	544	531	519	506	494	482		

Table 92 (*Continued*)
Cologarithms of Numbers

No.		0	1	2	3	4	5	6	7	8	9	P.P.	
350	.45	593	581	568	556	544	531	519	506	494	482		13
1		469	457	445	432	420	407	395	383	370	358	1	1
2		346	333	321	309	296	284	272	259	247	235	2	3
3		223	210	198	186	173	161	149	136	124	112	3	4
4		100	087	075	063	051	038	026	014	002	*989	4	5
5	.44	977	965	953	940	928	916	904	892	879	867	5	7
6		855	843	831	818	806	794	782	770	758	745	6	8
7		733	721	709	697	685	672	660	648	636	624	7	9
8		612	600	587	575	563	551	539	527	515	503	8	10
9		491	478	466	454	442	430	418	406	394	382	9	12
360		370	358	346	334	322	309	297	285	273	261		12
1		249	237	225	213	201	189	177	165	153	141	1	1
2		129	117	105	093	081	069	057	045	033	021	2	2
3		009	*997	*985	*973	*962	*950	*938	*926	*914	*902	3	4
4	.43	890	878	866	854	842	830	818	806	795	783	4	5
5		771	759	747	735	723	711	699	688	676	664	5	6
6		652	640	628	616	604	593	581	569	557	545	6	7
7		533	522	510	498	486	474	462	451	439	427	7	8
8		415	403	392	380	368	356	344	333	321	309	8	10
9		297	286	274	262	250	239	227	215	203	192	9	11
370		180	168	156	145	133	121	109	098	086	*074		11
1		063	051	039	028	016	004	*992	*981	*969	957	1	1
2	.42	946	934	922	911	899	887	876	864	852	841	2	2
3		829	817	806	794	783	771	759	748	736	724	3	3
4		713	701	690	678	666	655	643	632	620	608	4	4
5		597	585	574	562	551	539	527	516	504	493	5	6
6		481	470	458	447	435	424	412	400	389	377	6	7
7		366	354	343	331	320	308	297	285	274	262	7	8
8		251	239	228	216	205	193	182	170	159	148	8	9
9		136	125	113	102	090	079	067	056	045	033	9	10
380		022	010	*999	*987	*976	*965	*953	*942	*930	*919		10
1	.41	908	896	885	873	862	851	839	828	816	805	1	1
2		794	782	771	760	748	737	726	714	703	691	2	2
3		680	669	657	646	635	623	612	601	590	578	3	3
4		567	556	544	533	522	510	499	488	476	465	4	4
5		454	443	431	420	409	398	386	375	364	353	5	5
6		341	330	319	308	296	285	274	263	251	240	6	6
7		229	218	206	195	184	173	162	150	139	128	7	7
8		117	106	094	083	072	061	050	039	027	016	8	8
9		005	*994	*983	*972	*960	*949	*938	*927	*916	*905	9	9
390	.40	894	882	871	860	849	838	827	816	805	793		
1		782	771	760	749	738	727	716	705	694	682		
2		671	660	649	638	627	616	605	594	583	572		
3		561	550	539	528	517	506	494	483	472	461		
4		450	439	428	417	406	395	384	373	362	351		
5		340	329	318	307	296	285	274	263	252	241		
6		230	220	209	198	187	176	165	154	143	132		
7		121	110	099	088	077	066	055	044	034	*023		
8		012	001	*990	*979	*968	*957	*946	*935	*924	914		
9	.39	903	892	881	870	859	848	837	827	816	805		
400		794	783	772	761	751	740	729	718	707	696		

TABLE 92 (*Continued*)

COLOGARITHMS OF NUMBERS

No.	0	1	2	3	4	5	6	7	8	9	P.P.	
400	.39 794	783	772	761	751	740	729	718	707	696		
1	686	675	664	653	642	631	621	610	599	588		
2	577	567	556	545	534	523	513	502	491	480		
3	469	459	448	437	426	416	405	394	383	373		
4	362	351	340	330	319	308	297	287	276	265		
5	254	244	233	222	212	201	190	179	169	158		**11**
6	147	137	126	115	105	094	083	073	062	051	1	1
7	041	030	019	009	*998	*987	*977	*966	*955	*945	2	2
8	.38 934	923	913	902	891	881	870	860	849	838	3	3
9	828	817	806	796	785	775	764	753	743	732	4	4
410	722	711	700	690	679	669	658	648	637	626	5	6
1	616	605	595	584	574	563	552	542	531	521	6	7
2	510	500	489	479	468	458	447	437	426	416	7	8
3	405	394	384	373	363	352	342	331	321	310	8	9
4	300	289	279	269	258	248	237	227	216	206	9	10
5	195	185	174	164	153	143	132	122	112	101		
6	091	080	070	059	049	038	028	018	007	*997		
7	.37 986	976	966	955	945	934	924	914	903	893		
8	882	872	862	851	841	830	820	810	799	789		
9	779	768	758	748	737	727	716	706	696	685		
420	675	665	654	644	634	623	613	603	592	582		**10**
1	572	561	551	541	531	520	510	500	489	479	1	1
2	469	458	448	438	428	417	407	397	387	376	2	2
3	366	356	345	335	325	315	304	294	284	274	3	3
4	263	253	243	233	222	212	202	192	182	171	4	4
5	161	151	141	130	120	110	100	090	079	069	5	5
6	059	049	039	028	018	008	*998	*988	*978	*967	6	6
7	.36 957	947	937	927	917	906	896	886	876	866	7	7
8	856	845	835	825	815	805	795	785	775	764	8	8
9	754	744	734	724	714	704	694	683	673	663	9	9
430	653	643	633	623	613	603	593	583	572	562		
1	552	542	532	522	512	502	492	482	472	462		
2	452	442	432	421	411	401	391	381	371	361		
3	351	341	331	321	311	301	291	281	271	261		
4	251	241	231	221	211	201	191	181	171	161		
5	151	141	131	121	111	101	091	081	071	061		**9**
6	051	041	031	021	012	002	*992	*982	*972	*962	1	1
7	.35 952	942	932	922	912	902	892	882	872	863	2	2
8	853	843	833	823	813	803	793	783	773	763	3	3
9	754	744	734	724	714	704	694	684	674	665	4	4
440	655	645	635	625	615	605	596	586	576	566	5	5
1	556	546	536	527	517	507	497	487	477	468	6	5
2	458	448	438	428	418	409	399	389	379	369	7	6
3	360	350	340	330	320	311	301	291	281	271	8	7
4	262	252	242	232	223	213	203	193	184	174	9	8
5	164	154	144	135	125	115	105	096	086	076		
6	067	057	047	037	028	018	008	*998	*989	*979		
7	.34 969	960	950	940	930	921	911	901	892	882		
8	872	863	853	843	833	824	814	804	795	785		
9	775	766	756	746	737	727	717	708	698	688		
450	679	669	659	650	640	631	621	611	602	592		

TABLE 92 (*Continued*)

COLOGARITHMS OF NUMBERS

No.	0	1	2	3	4	5	6	7	8	9	P.P.	
450	.34 679	669	659	650	640	631	621	611	602	592		
1	582	573	563	553	544	534	525	515	505	496		
2	486	477	467	457	448	438	429	419	409	400		
3	390	381	371	361	352	342	333	323	314	304		
4	294	285	275	266	256	247	237	228	218	208		
5	199	189	180	170	161	151	142	132	123	113		10
6	104	094	084	075	065	056	046	037	027	018	1	1
7	008	*999	*989	*980	*970	*961	*951	*942	*932	*923	2	2
8	.33 913	904	894	885	876	866	857	847	838	828	3	3
9	819	809	800	790	781	771	762	753	743	734	4	4
460	724	715	705	696	686	677	668	658	649	639	5	5
1	630	620	611	602	592	583	573	564	555	545	6	6
2	536	526	517	508	498	489	479	470	461	451	7	7
3	442	433	423	414	404	395	386	376	367	358	8	8
4	348	339	329	320	311	301	292	283	273	264	9	9
5	255	245	236	227	217	208	199	189	180	171		
6	161	152	143	133	124	115	106	096	087	078		
7	068	059	050	040	031	022	013	003	*994	*985		
8	.32 975	966	957	948	938	929	920	911	901	892		
9	883	873	864	855	846	836	827	818	809	799		
470	790	781	772	763	753	744	735	726	716	707		9
1	698	689	679	670	661	652	643	633	624	615	1	1
2	606	597	587	578	569	560	551	541	532	523	2	2
3	514	505	496	486	477	468	459	450	440	431	3	3
4	422	413	404	395	386	376	367	358	349	340	4	4
5	331	321	312	303	294	285	276	267	258	248	5	5
6	239	230	221	212	203	194	185	175	166	157	7	6
7	148	139	130	121	112	103	094	084	075	066	8	7
8	057	048	039	030	021	012	003	*994	*985	*976	9	8
9	.31 966	957	948	939	930	921	912	903	894	885		
480	876	867	858	849	840	831	822	813	804	795		
1	785	776	767	758	749	740	731	722	713	704		
2	695	686	677	668	659	650	641	632	623	614		
3	605	596	587	578	569	560	551	542	533	524		
4	515	506	498	489	480	471	462	453	444	435		
5	426	417	408	399	390	381	372	363	354	345		8
6	336	327	319	310	301	292	283	274	265	256	1	1
7	247	238	229	220	211	203	194	185	176	167	2	2
8	158	149	140	131	122	114	105	096	087	078	3	2
9	069	060	051	042	034	025	016	007	*998	*989	4	3
490	.30 980	972	963	954	945	936	927	918	910	901	5	4
1	892	883	874	865	856	848	839	830	821	812	6	5
2	803	795	786	777	768	759	751	742	733	724	7	6
3	715	706	698	689	680	671	662	654	645	636	8	6
4	627	619	610	601	592	583	575	566	557	548	9	7
5	539	531	522	513	504	496	487	478	469	461		
6	452	443	434	426	417	408	399	391	382	373		
7	364	356	347	338	329	321	312	303	295	286		
8	277	268	260	251	242	233	225	216	207	199		
9	190	181	173	164	155	146	138	129	120	112		
500	103	094	086	077	068	060	051	042	034	025		

Table 92 (*Continued*)

Cologarithms of Numbers

No.	0	1	2	3	4	5	6	7	8	9	P.P.	
500	.30 103	094	086	077	068	060	051	042	034	025		
1	016	008	*999	*990	*982	*973	*964	*956	*947	*938		
2	.29 930	921	912	904	895	886	878	869	860	852		
3	843	835	826	817	809	800	791	783	774	766		
4	757	748	740	731	722	714	705	697	688	679		
5	671	662	654	645	636	628	619	611	602	594		9
6	585	576	568	559	551	542	533	525	516	508	1	1
7	499	491	482	474	465	456	448	439	431	422	2	2
8	414	405	397	388	379	371	362	354	345	337	3	3
9	328	320	311	303	294	286	277	269	260	251	4	4
510	243	234	226	217	209	200	192	183	175	166	5	5
1	158	149	141	132	124	115	107	098	090	081	6	5
2	073	065	056	048	039	031	022	014	005	*997	7	6
3	.28 988	980	971	963	954	946	937	929	921	912	8	7
4	904	895	887	878	870	861	853	845	836	828	9	8
5	819	811	802	794	786	777	769	760	752	743		
6	735	727	718	710	701	693	685	676	668	659		
7	651	643	634	626	617	609	601	592	584	575		
8	567	559	550	542	534	525	517	508	500	492		
9	483	475	467	458	450	441	433	425	416	408		
520	400	391	383	375	366	358	350	341	333	325		8
1	316	308	300	291	283	275	266	258	250	241	1	1
2	233	225	216	208	200	191	183	175	166	158	2	2
3	150	142	133	125	117	108	100	092	083	075	3	2
4	067	059	050	042	034	025	017	009	001	*992	4	3
5	.27 984	976	968	959	951	943	934	926	918	910	5	4
6	901	893	885	877	868	860	852	844	835	827	6	5
7	819	811	802	794	786	778	770	761	753	745	7	6
8	737	728	720	712	704	696	687	679	671	663	8	6
9	654	646	638	630	622	613	605	597	589	581	9	7
530	572	564	556	548	540	531	523	515	507	499		
1	491	482	474	466	458	450	442	433	425	417		
2	409	401	393	384	376	368	360	352	344	335		
3	327	319	311	303	295	287	278	270	262	254		
4	246	238	230	221	213	205	197	189	181	173		
5	165	157	148	140	132	124	116	108	100	092		7
6	084	075	067	059	051	043	035	027	019	011	1	1
7	003	*994	*986	*978	*970	*962	*954	*946	*938	*930	2	1
8	.26 922	914	906	898	889	881	873	865	857	849	3	2
9	841	833	825	817	809	801	793	785	777	769	4	3
540	761	753	745	737	728	720	712	704	696	688	5	4
1	680	672	664	656	648	640	632	624	616	608	6	4
2	600	592	584	576	568	560	552	544	536	528	7	5
3	520	512	504	496	488	480	472	464	456	448	8	6
4	440	432	424	416	408	400	392	384	376	368	9	6
5	360	352	344	336	328	321	313	305	297	289		
6	281	273	265	257	249	241	233	225	217	209		
7	201	193	185	177	170	162	154	146	138	130		
8	122	114	106	098	090	082	074	067	059	051		
9	043	035	027	019	011	003	*995	*987	*980	*972		
550	.25 964	956	948	940	932	924	916	908	901	893		

Table 92 (*Continued*)
Cologarithms of Numbers

No.	0	1	2	3	4	5	6	7	8	9	P.P.	
550	.25 964	956	948	940	932	924	916	908	901	893		
1	885	877	869	861	853	845	838	830	822	814		
2	806	798	790	782	775	767	759	751	743	735		
3	727	720	712	704	696	688	680	673	665	657		
4	649	641	633	626	618	610	602	594	586	579		
5	571	563	555	547	539	532	524	516	508	500		
6	493	485	477	469	461	453	446	438	430	422		
7	414	497	399	391	383	376	368	360	352	344		
8	337	329	321	313	305	298	290	282	274	267		
9	259	251	243	236	228	220	212	204	197	189		8
560	181	173	166	158	150	142	135	127	119	111	1	1
1	104	096	088	080	073	065	057	050	042	034	2	2
2	026	019	011	003	*995	*988	*980	*972	*965	*957	3	2
3	.24 949	941	934	926	918	911	903	895	887	880	4	3
4	872	864	857	849	841	834	826	818	811	803	5	4
5	795	787	780	772	764	757	749	741	734	726	6	5
6	718	711	703	695	688	680	672	665	657	649	7	6
7	642	634	626	619	611	603	596	588	580	573	8	6
8	565	558	550	542	535	527	519	512	504	496	9	7
9	489	481	474	466	458	451	443	435	428	420		
570	413	405	397	390	382	374	367	359	352	344		
1	336	329	321	314	306	298	291	283	276	268		
2	260	253	245	238	230	222	215	207	200	192		
3	185	177	169	162	154	147	139	132	124	116		
4	109	101	094	086	079	071	063	056	048	041		
5	033	026	018	011	003	*995	*988	*980	*973	*965		
6	.23 958	950	943	935	928	920	913	905	897	890		
7	882	875	867	860	852	845	837	830	822	815		
8	807	800	792	785	777	770	762	755	747	740		
9	732	725	717	710	702	695	687	680	672	665		7
580	657	650	642	635	627	620	612	605	597	590	1	1
1	582	575	567	560	552	545	538	530	523	515	2	1
2	508	500	493	485	478	470	463	455	448	441	3	2
3	433	426	418	411	403	396	388	381	374	366	4	3
4	359	351	344	336	329	322	314	307	299	292	5	4
5	284	277	270	262	255	247	240	232	225	218	6	4
6	210	203	195	188	181	173	166	158	151	144	7	5
7	136	129	121	114	107	099	092	084	077	070	8	6
8	062	055	047	040	033	025	018	011	003	*996	9	6
9	.22 988	981	974	966	959	952	944	937	930	922		
590	915	907	900	893	885	878	871	863	856	849		
1	841	834	827	819	812	805	797	790	783	775		
2	768	760	753	746	738	731	724	717	709	702		
3	695	687	680	673	665	658	651	643	636	629		
4	621	614	607	599	592	585	578	570	563	556		
5	548	541	534	526	519	512	505	497	490	483		
6	475	468	461	454	446	439	432	424	417	410		
7	403	395	388	381	373	366	359	352	344	337		
8	330	323	315	308	301	294	286	279	272	265		
9	257	250	243	236	228	221	214	207	199	192		
600	185	178	170	163	156	149	141	134	127	120		

TABLE 92 (*Continued*)

COLOGARITHMS OF NUMBERS

No.	0	1	2	3	4	5	6	7	8	9	P.P.	
600	.22 185	178	170	163	156	149	141	134	127	120		
1	113	105	098	091	084	076	069	062	055	048		
2	040	033	026	019	012	004	*997	*990	*983	*975		
3	.21 968	961	954	947	939	932	925	918	911	903		
4	896	889	882	875	868	860	853	846	839	832		
5	824	817	810	803	796	789	781	774	767	760		8
6	753	746	738	731	724	717	710	703	695	688	1	1
7	681	674	667	660	653	645	638	631	624	617	2	2
8	610	602	595	588	581	574	567	560	553	545	3	2
9	538	531	524	517	510	503	496	488	481	474	4	3
610	467	460	453	446	439	431	424	417	410	403	5	4
1	396	389	382	375	367	360	353	346	339	332	6	5
2	325	318	311	304	296	289	282	275	268	261	7	6
3	254	247	240	233	226	219	211	204	197	190	8	6
4	183	176	169	162	155	148	141	134	127	120	9	7
5	112	105	098	091	084	077	070	063	056	049		
6	042	035	028	021	014	007	000	*993	*986	*979		
7	.20 971	964	957	950	943	936	929	922	915	908		
8	901	894	887	880	873	866	859	852	845	838		
9	831	824	817	810	803	796	789	782	775	768		
620	761	754	747	740	733	726	719	712	705	698		7
1	691	684	677	670	663	656	649	642	635	628	1	1
2	621	614	607	600	593	586	579	572	565	558	2	1
3	551	544	537	530	523	516	509	502	495	489	3	2
4	482	475	468	461	454	447	440	433	426	419	4	3
5	412	405	398	391	384	377	370	363	356	350	5	4
6	343	336	329	322	315	308	301	294	287	280	6	4
7	273	266	259	252	246	239	232	225	218	211	7	5
8	204	197	190	183	176	169	163	156	149	142	8	6
9	135	128	121	114	107	100	094	087	080	073	9	6
630	066	059	052	045	038	031	025	018	011	004		
1	.19 997	990	983	976	970	963	956	949	942	935		
2	928	921	915	908	901	894	887	880	873	866		
3	860	853	846	839	832	825	818	812	805	798		
4	791	784	777	771	764	757	750	743	736	729		
5	723	716	709	702	695	688	682	675	668	661		6
6	654	647	641	634	627	620	613	607	600	593	1	1
7	586	579	572	566	559	552	545	538	532	525	2	1
8	518	511	504	498	491	484	477	470	464	457	3	2
9	450	443	436	430	423	416	409	402	396	389	4	2
640	382	375	368	362	355	348	341	335	328	321	5	3
1	314	307	301	294	287	280	274	267	260	253	6	4
2	246	240	233	226	219	213	206	199	192	186	7	4
3	179	172	165	159	152	145	138	132	125	118	8	5
4	111	105	098	091	084	078	071	064	057	051	9	5
5	044	037	031	024	017	010	004	*997	*990	*983		
6	.18 977	970	963	957	950	943	936	930	923	916		
7	910	903	896	889	883	876	869	863	856	849		
8	842	836	829	822	816	809	802	796	789	782		
9	776	769	762	755	749	742	735	729	722	715		
650	709	702	695	689	682	675	669	662	655	649		

Table 92 (*Continued*)
Cologarithms of Numbers

No.	0	1	2	3	4	5	6	7		9	P.P.	
650	.18 709	702	695	689	682	675	669	662	655	649		
1	642	635	629	622	615	609	602	595	589	582		
2	575	569	562	555	549	542	535	529	522	515		
3	509	502	495	489	482	475	469	462	456	449		
4	442	436	429	422	416	409	402	396	389	383		
5	376	369	363	356	349	343	336	329	323	316		
6	310	303	296	290	283	277	270	263	257	250		
7	243	237	230	224	217	210	204	197	191	184		
8	177	171	164	158	151	144	138	131	125	118		
9	111	105	098	092	085	079	072	065	059	052		
660	046	039	032	026	019	013	006	000	*993	*986		7
1	.17 980	973	967	960	954	947	940	934	927	921	1	1
2	914	908	901	895	888	881	875	868	862	855	2	1
3	849	842	836	829	822	816	809	803	796	790	3	2
4	783	777	770	764	757	751	744	737	731	724	4	3
5	718	711	705	698	692	685	679	672	666	659	5	4
6	653	646	640	633	627	620	613	607	600	594	6	4
7	587	581	574	568	561	555	548	542	535	529	7	5
8	522	516	509	503	496	490	483	477	470	464	8	6
9	457	451	444	438	431	425	418	412	405	399	9	6
670	393	386	380	373	367	360	354	347	341	334		
1	328	321	315	308	302	295	289	282	276	270		
2	263	257	250	244	237	231	224	218	211	205		
3	198	192	186	179	173	166	160	153	147	140		
4	134	128	121	115	108	102	095	089	082	076		
5	070	063	057	050	044	037	031	025	018	012		
6	005	*999	*992	*986	*980	*973	*967	*960	*954	*948		
7	.16 941	935	928	922	915	909	903	896	890	883		
8	877	871	864	858	851	845	839	932	826	819		
9	813	807	800	794	787	781	775	768	762	755		
680	749	743	736	730	724	717	711	704	698	692		6
1	685	679	673	666	660	653	647	641	634	628	1	1
2	622	615	609	602	596	590	583	577	571	564	2	1
3	558	552	545	539	533	526	520	513	507	501	3	2
4	494	488	482	475	469	463	456	450	444	437	4	2
5	431	425	418	412	406	399	393	387	380	374	5	3
6	368	361	355	349	342	336	330	323	317	311	6	4
7	304	298	292	285	279	273	266	260	254	247	7	4
8	241	235	229	222	216	210	203	197	191	184	8	5
9	178	172	165	159	153	147	140	134	128	121	9	5
690	115	109	103	096	090	084	077	071	065	058		
1	052	046	040	033	027	021	015	008	002	*996		
2	.15 989	983	977	971	964	958	952	945	939	933		
3	927	920	914	908	902	895	889	883	877	870		
4	864	858	852	845	839	833	827	820	814	808		
5	802	795	789	783	777	770	764	758	752	745		
6	739	733	727	720	714	708	702	695	689	683		
7	677	670	664	658	652	646	639	633	627	621		
8	614	608	602	596	590	583	577	571	565	558		
9	552	546	540	534	527	521	515	509	503	496		
700	490	484	478	472	465	459	453	447	441	434		

Table 92 (*Continued*)

Cologarithms of Numbers

No.		0	1	2	3	4	5	6	7	8	9	P.P.	
700	.15	490	484	478	472	465	459	453	447	441	434		
1		428	422	416	410	403	397	391	385	379	372		
2		366	360	354	348	342	335	329	323	317	311		
3		304	298	292	286	280	274	267	261	255	249		
4		243	237	230	224	218	212	206	200	193	187		
5		181	175	169	163	156	150	144	138	132	126	7	
6		120	113	107	101	095	089	083	076	070	064	1	1
7		058	052	046	040	033	027	021	015	009	003	2	1
8	.14	997	991	984	978	972	966	960	954	948	942	3	2
9		935	929	923	917	911	905	899	893	886	880	4	3
710		874	868	862	856	850	844	837	831	825	819	5	4
1		813	807	801	795	789	783	776	770	764	758	6	4
2		752	746	740	734	728	722	715	709	703	697	7	5
3		691	685	679	673	667	661	655	648	642	636	8	6
4		630	624	618	612	606	600	594	588	582	575	9	6
5		569	563	557	551	545	539	533	527	521	515		
6		509	503	497	491	484	478	472	466	460	454		
7		448	442	436	430	424	418	412	406	400	394		
8		388	382	375	369	363	357	351	345	339	333		
9		327	321	315	309	303	297	291	285	279	273		
720		267	261	255	249	243	237	231	225	219	212	6	
1		206	200	194	188	182	176	170	164	158	152	1	1
2		146	140	134	128	122	116	110	104	098	092	2	1
3		086	080	074	068	062	056	050	044	038	032	3	2
4		026	020	014	008	002	*996	*990	*984	*978	*972	4	2
5	.13	966	960	954	948	942	936	930	924	918	912	5	3
6		906	900	894	888	882	876	870	864	859	853	6	4
7		847	841	835	829	823	817	811	805	799	793	7	4
8		787	781	775	769	763	757	751	745	739	733	8	5
9		727	721	715	709	703	697	692	686	680	674	9	5
730		668	662	656	650	644	638	632	626	620	614		
1		608	602	596	590	585	579	573	567	561	555		
2		549	543	537	531	525	519	513	507	501	496		
3		490	484	478	472	466	460	454	448	442	436		
4		430	424	419	413	407	401	395	389	383	377		
5		371	365	359	354	348	342	336	330	324	318	5	
6		312	306	300	295	289	283	277	271	265	259	1	1
7		253	247	241	236	230	224	218	212	206	200	2	1
8		194	188	183	177	171	165	159	153	147	141	3	2
9		136	130	124	118	112	106	100	094	089	083	4	2
740		077	071	065	059	053	047	042	036	030	024	5	3
1		018	012	006	001	*995	*989	*983	*977	*971	*965	6	3
2	.12	960	954	948	942	936	930	925	919	913	907	7	4
3		901	895	889	884	878	872	866	860	854	849	8	4
4		843	837	831	825	819	814	808	802	796	790	9	5
5		784	779	773	767	761	755	749	744	738	732		
6		726	720	714	709	703	697	691	685	680	674		
7		668	662	656	651	645	639	633	627	621	616		
8		610	604	598	592	587	581	575	569	563	558		
9		552	546	540	534	529	523	517	511	505	500		
750		494	488	482	477	471	465	459	453	448	442		

TABLE 92 (*Continued*)

COLOGARITHMS OF NUMBERS

No.	0	1	2	3	4	5	6	7	8	9	P.P.
750	.12 494	488	482	477	471	465	459	453	448	442	
1	436	430	424	419	413	407	401	396	390	384	
2	378	372	367	361	355	349	344	338	332	326	
3	321	315	309	303	297	292	286	280	274	269	
4	263	257	251	246	240	234	228	223	217	211	
5	205	200	194	188	182	177	171	165	159	154	
6	148	142	136	131	125	119	113	108	102	096	
7	090	085	079	073	067	062	056	050	045	039	
8	033	027	022	016	010	004	*999	*993	*987	*982	
9	.11 976	970	964	959	953	947	942	936	930	924	
760	919	913	907	902	896	890	884	879	873	867	6
1	862	856	850	844	839	833	827	822	816	810	1 1
2	805	799	793	787	782	776	770	765	759	753	2 1
3	748	742	736	730	725	719	713	708	702	696	3 2
4	691	685	679	674	668	662	657	651	645	640	4 2
5	634	628	623	617	611	605	600	594	588	583	5 3
6	577	571	566	560	554	549	543	537	532	526	6 4
7	520	515	509	503	498	492	487	481	475	470	7 4
8	464	458	453	447	441	436	430	424	419	413	8 5
9	407	402	396	390	385	379	373	368	362	357	9 5
770	351	345	340	334	328	323	317	311	306	300	
1	295	289	283	278	272	266	261	255	250	244	
2	238	233	227	221	216	210	205	199	193	188	
3	182	176	171	165	160	154	148	143	137	132	
4	126	120	115	109	103	098	092	087	081	075	
5	070	064	059	053	047	042	036	031	025	019	
6	014	008	003	*997	*991	*986	*980	*975	*969	*963	
7	.10 958	952	947	941	936	930	924	919	913	908	
8	902	896	891	885	880	874	869	863	857	852	
9	846	841	835	830	824	818	813	807	802	796	
780	791	785	779	774	768	763	757	752	746	740	5
1	735	729	724	718	713	707	702	696	690	685	1 1
2	679	674	668	663	657	652	646	640	635	629	2 1
3	624	618	613	607	602	596	591	585	579	574	3 2
4	568	563	557	552	546	541	535	530	524	519	4 2
5	513	508	502	496	491	485	480	474	469	463	5 3
6	458	452	447	441	436	430	425	419	414	408	6 3
7	403	397	391	386	380	375	369	364	358	353	7 4
8	347	342	336	331	325	320	314	309	303	298	8 4
9	292	287	281	276	270	265	259	254	248	243	9 5
790	237	232	226	221	215	210	204	199	193	188	
1	182	177	171	166	160	155	149	144	138	133	
2	127	122	117	111	106	100	095	089	084	078	
3	073	067	062	056	051	045	040	034	029	023	
4	018	012	007	002	*996	*991	*985	*980	*974	*969	
5	.09 963	958	952	947	941	936	931	925	920	914	
6	909	903	898	892	887	881	876	871	865	860	
7	854	849	843	838	832	827	821	816	811	805	
8	800	794	789	783	778	773	767	762	756	751	
9	745	740	734	729	724	718	713	707	702	696	
800	691	686	680	675	669	664	658	653	648	642	

TABLE 92 (*Continued*)
COLOGARITHMS OF NUMBERS

No.	0	1	2	3	4	5	6	7	8	9	P.P.
800	.09 691	686	680	675	669	664	658	653	648	642	
1	637	631	626	620	615	610	604	599	593	588	
2	583	577	572	566	561	555	550	545	539	534	
3	528	523	518	512	507	501	496	491	485	480	
4	474	469	464	458	453	447	442	437	431	426	
5	420	415	410	404	399	393	388	383	377	372	
6	366	361	356	350	345	340	334	329	323	318	
7	313	307	302	297	291	286	280	275	270	264	
8	259	253	248	243	237	232	227	221	216	211	
9	205	200	194	189	184	178	173	168	162	157	
810	151	146	141	135	130	125	119	114	109	103	6
1	098	093	087	082	076	071	066	060	055	050	1 1
2	044	039	034	028	023	018	012	007	002	*996	2 1
3	.08 991	986	980	975	970	964	959	954	948	943	3 2
4	938	932	927	922	916	911	906	900	895	890	4 2
5	884	879	874	868	863	858	852	847	842	836	5 3
6	831	826	820	815	810	804	799	794	788	783	6 4
7	778	772	767	762	757	751	746	741	735	730	7 4
8	725	719	714	709	703	698	693	688	682	677	8 5
9	672	666	661	656	650	645	640	635	629	624	9 5
820	619	613	608	603	597	592	587	582	576	571	
1	566	560	555	550	545	539	534	529	523	518	
2	513	508	502	497	492	486	481	476	471	465	
3	460	455	449	444	439	434	428	423	418	413	
4	407	402	397	391	386	381	376	370	365	360	
5	355	349	344	339	334	328	323	318	313	307	
6	302	297	291	286	281	276	270	265	260	255	
7	249	244	239	234	228	223	218	213	207	202	
8	197	192	186	181	176	171	166	160	155	150	
9	145	139	134	129	124	118	113	108	103	097	
830	092	087	082	076	071	066	061	056	050	045	5
1	040	035	029	024	019	014	009	003	*998	*993	1 1
2	.07 988	982	977	972	967	962	956	951	946	941	2 1
3	935	930	925	920	915	909	904	899	894	889	3 2
4	883	878	873	868	863	857	852	847	842	837	4 2
5	831	826	821	816	811	805	800	795	790	785	5 3
6	779	774	769	764	759	753	748	743	738	733	6 3
7	727	722	717	712	707	702	696	691	686	681	7 4
8	676	670	665	660	655	650	645	639	634	629	8 4
9	624	619	613	608	603	598	593	588	582	577	9 5
840	572	567	562	557	551	546	541	536	531	526	
1	520	515	510	505	500	495	489	484	479	474	
2	469	464	458	453	448	443	438	433	428	422	
3	417	412	407	402	397	391	386	381	376	371	
4	366	361	355	350	345	340	335	330	325	319	
5	314	309	304	299	294	289	284	278	273	268	
6	263	258	253	248	242	237	232	227	222	217	
7	212	207	201	196	191	186	181	176	171	166	
8	160	155	150	145	140	135	130	125	119	114	
9	109	104	099	094	089	084	079	073	068	063	
850	058	053	048	043	038	033	027	022	017	012	

TABLE 92 (*Continued*)

COLOGARITHMS OF NUMBERS

No.	0	1	2	3	4	5	6	7	8	9	P.P.
850	.07 058	053	048	043	038	033	027	022	017	012	
1	007	002	*997	*992	*987	*982	*976	*971	*966	*961	
2	.06 956	951	946	941	936	931	925	920	915	910	
3	905	900	895	890	885	880	875	869	864	859	
4	854	849	844	839	834	829	824	819	814	808	
5	803	798	793	788	783	778	773	768	763	758	6
6	753	748	742	737	732	727	722	717	712	707	1 1
7	702	697	692	687	682	677	672	666	661	656	2 1
8	651	646	641	636	631	626	621	616	611	606	3 2
9	601	596	591	586	580	575	570	565	560	555	4 2
860	550	545	540	535	530	525	520	515	510	505	5 3
1	500	495	490	485	480	474	469	464	459	454	6 4
2	449	444	439	434	429	424	419	414	409	404	7 4
3	399	394	389	384	379	374	369	364	359	354	8 5
4	349	344	339	334	329	324	318	313	308	303	9 5
5	298	293	288	283	278	273	268	263	258	253	
6	248	243	238	233	228	223	218	213	298	203	
7	198	193	188	183	178	173	168	163	158	153	
8	148	143	138	133	128	123	118	113	108	103	
9	098	093	088	083	078	073	068	063	058	053	
870	048	043	038	033	028	023	018	013	008	003	5
1	.05 998	993	988	983	978	973	968	963	958	953	1 1
2	948	943	938	933	928	923	918	914	909	904	2 1
3	899	894	889	884	879	874	869	864	859	954	3 2
4	849	844	839	834	829	824	819	814	809	804	4 2
5	799	794	789	784	779	774	769	764	760	755	5 3
6	750	745	740	735	730	725	720	715	710	705	6 3
7	700	695	690	685	680	675	670	665	660	655	7 4
8	651	646	641	636	631	626	621	616	611	606	8 4
9	601	596	591	586	581	576	571	567	562	557	9 5
880	552	547	542	537	532	527	522	517	512	507	
1	502	497	493	488	483	478	473	468	463	458	
2	453	448	443	438	433	429	424	419	414	409	
3	404	399	394	389	384	379	374	370	365	360	
4	355	350	345	340	335	330	325	320	315	311	
5	306	301	296	291	286	281	276	271	266	262	4
6	257	252	247	242	237	232	227	222	217	213	1 0
7	208	203	198	193	188	183	178	173	168	164	2 1
8	159	154	149	144	139	134	129	124	120	115	3 1
9	110	105	100	095	090	085	081	076	071	066	4 2
890	061	056	051	046	041	037	032	027	022	017	5 2
1	012	007	002	*998	*993	*988	*983	*978	*973	*968	6 2
2	.04 964	959	954	949	944	939	934	929	925	920	7 3
3	915	910	905	900	895	891	886	881	876	871	8 3
4	866	861	857	852	847	842	837	832	827	823	9 4
5	818	813	808	803	798	793	789	784	779	774	
6	769	764	760	755	750	745	740	735	730	726	
7	721	716	711	706	701	697	692	687	682	677	
8	672	668	663	658	653	648	643	639	634	629	
9	624	619	614	610	605	600	595	590	585	581	
900	576	571	566	561	556	552	547	542	537	532	

Table 92 (*Continued*)
Cologarithms of Numbers

No.	0	1	2	3	4	5	6	7	8	9	P.P.
900	.04 576	571	566	561	556	552	547	542	537	532	
1	528	523	518	513	508	503	499	494	489	484	
2	479	475	470	465	460	455	450	446	441	436	
3	431	426	422	417	412	407	402	398	393	388	
4	383	378	374	369	364	359	354	350	345	340	
5	335	330	326	321	316	311	306	302	297	292	
6	287	282	278	273	268	263	258	254	249	244	
7	239	234	230	225	220	215	211	206	201	196	
8	191	187	182	177	172	168	163	158	153	148	
9	144	139	134	129	125	120	115	110	105	101	
910	096	091	086	082	077	072	067	062	058	053	5
1	048	043	039	034	029	024	020	015	010	005	1 1
2	001	*996	*991	*986	*981	*977	*972	*967	*962	*958	2 1
3	.03 953	948	943	939	934	929	924	920	915	910	3 2
4	905	901	896	891	886	882	877	872	867	863	4 2
5	858	853	848	844	839	834	829	825	820	815	5 3
6	810	806	801	796	791	787	782	777	773	768	6 3
7	763	758	754	749	744	739	735	730	725	720	7 4
8	716	711	706	702	697	692	687	683	678	673	8 4
9	668	664	659	654	650	645	640	635	631	626	9 5
920	621	616	612	607	602	598	593	588	583	579	
1	574	569	565	560	555	550	546	541	536	532	
2	527	522	517	513	508	503	499	494	489	485	
3	480	475	470	466	461	456	452	447	442	438	
4	433	428	423	419	414	409	405	400	395	391	
5	386	381	376	372	367	362	358	353	348	344	
6	339	334	330	325	320	315	311	306	301	297	
7	292	287	283	278	273	269	264	259	255	250	
8	245	241	236	231	226	222	217	212	208	203	
9	198	194	189	184	180	175	170	166	161	156	
930	152	147	142	138	133	128	124	119	114	110	4
1	105	100	096	091	086	082	077	072	068	063	1 0
2	058	054	049	044	040	035	030	026	021	016	2 1
3	012	007	003	*998	*993	*989	*984	*979	*975	*970	3 1
4	.02 965	961	956	951	947	942	937	933	928	923	4 2
5	919	914	910	905	900	896	891	886	882	877	5 2
6	872	868	863	858	854	849	845	840	835	831	6 2
7	826	821	817	812	808	803	798	794	789	784	7 3
8	780	775	770	766	761	757	752	747	743	738	8 3
9	733	729	724	720	715	710	706	701	696	692	9 4
940	687	683	678	673	669	664	660	655	650	646	
1	641	636	632	627	623	618	613	609	604	600	
2	505	590	586	581	576	572	567	563	558	553	
3	549	544	540	535	530	526	521	517	512	507	
4	503	498	494	489	484	480	475	471	466	461	
5	457	452	448	443	438	434	429	425	420	415	
6	411	406	402	397	393	388	383	379	374	370	
7	365	360	356	351	347	342	337	333	328	324	
8	319	315	310	305	301	296	292	287	283	278	
9	273	269	264	260	255	251	246	241	237	232	
950	228	223	218	214	209	205	200	196	191	187	

Table 92 (*Concluded*)
Cologarithms of Numbers

No.	0	1	2	3	4	5	6	7	8	9	P.P.
950	.02 228	223	218	214	209	205	200	196	191	187	
1	182	177	173	168	164	159	155	150	145	141	
2	136	132	127	123	118	114	109	104	100	095	
3	091	086	082	077	072	068	063	059	054	050	
4	045	041	036	032	027	022	018	013	009	004	
5	000	*995	*991	*986	*981	*977	*972	*968	*963	*959	
6	.01 954	950	945	941	936	932	927	922	918	913	
7	909	904	900	895	891	886	882	877	873	868	
8	863	859	854	850	845	841	836	832	827	823	
9	818	814	809	805	800	796	791	786	782	777	
960	773	768	764	759	755	750	746	741	737	732	5
1	728	723	719	714	710	705	701	696	692	687	1 1
2	682	678	673	669	664	660	655	651	646	642	2 1
3	637	633	628	624	619	615	610	606	601	597	3 2
4	592	588	583	579	574	570	565	561	556	552	4 2
5	547	543	538	534	529	525	520	516	511	507	5 3
6	502	498	493	489	484	480	475	471	466	462	6 3
7	457	453	448	444	439	435	430	426	421	417	7 4
8	412	408	403	399	395	390	386	381	377	372	8 4
9	368	363	359	354	350	345	341	336	332	327	9 5
970	323	318	314	309	305	300	296	291	287	283	
1	278	274	269	265	260	256	251	247	242	238	
2	233	229	224	220	216	211	207	202	198	193	
3	189	184	180	175	171	166	162	157	153	149	
4	144	140	135	131	126	122	117	113	108	104	
5	100	095	091	086	082	077	073	068	064	059	
6	055	051	046	042	037	033	028	024	019	015	
7	011	006	002	*997	*993	*988	*984	*979	*975	*971	
8	.00 966	962	957	953	948	944	939	935	931	926	
9	922	917	913	908	904	900	895	891	886	882	
980	877	873	869	864	860	855	851	846	842	838	4
1	833	829	824	820	815	811	807	802	798	793	1 0
2	789	784	780	776	771	767	762	758	753	749	2 1
3	745	740	736	731	727	723	718	714	709	705	3 1
4	700	696	692	687	683	678	674	670	665	661	4 2
5	656	652	648	643	639	634	630	626	621	617	5 2
6	612	608	604	599	595	590	586	581	577	573	6 2
7	568	564	559	555	551	546	542	537	533	529	7 3
8	524	520	516	511	507	502	498	494	489	485	8 3
9	480	476	472	467	463	458	454	450	445	441	9 4
990	436	432	428	423	419	415	410	406	401	397	
1	393	388	384	379	375	371	366	362	358	353	
2	349	344	340	336	331	327	323	318	314	309	
3	305	301	296	292	288	283	279	274	270	266	
4	261	257	253	248	244	240	235	231	226	222	
5	218	213	209	205	200	196	192	187	183	178	
6	174	170	165	161	157	152	148	144	139	135	
7	130	126	122	117	113	109	104	100	096	091	
8	087	083	078	074	070	065	061	056	052	048	
9	043	039	035	030	026	022	017	013	009	004	
1000	000										

TABLE 93.—NATURAL SINES AND COSINES

Degrees	SINES 0′	10′	20′	30′	40′	50′	60′	Cosines
0	0.00000	0.00291	0.00582	0.00873	0.01164	0.01454	0.01745	89
1	0.01745	0.02036	0.02327	0.02618	0.02908	0.03199	0.03490	88
2	0.03490	0.03781	0.04071	0.04362	0.04653	0.04943	0.05234	87
3	0.05234	0.05524	0.05814	0.06105	0.06395	0.06685	0.06976	86
4	0.06976	0.07266	0.07556	0.07846	0.08136	0.08426	0.08716	85
5	0.08716	0.09005	0.09295	0.09585	0.09874	0.10164	0.10453	84
6	0.10453	0.10742	0.11031	0.11320	0.11609	0.11898	0.12187	83
7	0.12187	0.12476	0.12764	0.13053	0.13341	0.13629	0.13917	82
8	0.13917	0.14205	0.14493	0.14781	0.15069	0.15356	0.15643	81
9	0.15643	0.15931	0.16218	0.16505	0.16792	0.17078	0.17365	80
10	0.17365	0.17651	0.17937	0.18224	0.18509	0.18795	0.19081	79
11	0.19081	0.19366	0.19652	0.19937	0.20222	0.20507	0.20791	78
12	0.20791	0.21076	0.21360	0.21644	0.21928	0.22212	0.22495	77
13	0.22495	0.22778	0.23062	0.23345	0.23627	0.23910	0.24192	76
14	0.24192	0.24474	0.24756	0.25038	0.25320	0.25601	0.25882	75
15	0.25882	0.26163	0.26443	0.26724	0.27004	0.27284	0.27564	74
16	0.27564	0.27843	0.28123	0.28402	0.28680	0.28959	0.29237	73
17	0.29237	0.29515	0.29793	0.30071	0.30348	0.30625	0.30902	72
18	0.30902	0.31178	0.31454	0.31730	0.32006	0.32282	0.32557	71
19	0.32557	0.32832	0.33106	0.33381	0.33655	0.33929	0.34202	70
20	0.34202	0.34475	0.34748	0.35021	0.35293	0.35565	0.35837	69
21	0.35837	0.36108	0.36379	0.36650	0.36921	0.37191	0.37461	68
22	0.37461	0.37730	0.37999	0.38268	0.38537	0.38805	0.39073	67
23	0.39073	0.39341	0.39608	0.39875	0.40142	0.40408	0.40674	66
24	0.40674	0.40939	0.41204	0.41469	0.41734	0.41998	0.42262	65
25	0.42262	0.42525	0.42788	0.43051	0.43313	0.43575	0.43837	64
26	0.43837	0.44098	0.44359	0.44620	0.44880	0.45140	0.45399	63
27	0.45399	0.45658	0.45917	0.46175	0.46433	0.46690	0.46947	62
28	0.46947	0.47204	0.47460	0.47716	0.47971	0.48226	0.48481	61
29	0.48481	0.48735	0.48989	0.49242	0.49495	0.49748	0.50000	60
30	0.50000	0.50252	0.50503	0.50754	0.51004	0.51254	0.51504	59
31	0.51504	0.51753	0.52002	0.52250	0.52498	0.52745	0.52992	58
32	0.52992	0.53238	0.53484	0.53730	0.53975	0.54220	0.54464	57
33	0.54464	0.54708	0.54951	0.55194	0.55436	0.55678	0.55919	56
34	0.55919	0.56160	0.56401	0.56641	0.56880	0.57119	0.57358	55
35	0.57358	0.57596	0.57833	0.58070	0.58307	0.58543	0.58779	54
36	0.58779	0.59014	0.59248	0.59482	0.59716	0.59949	0.60182	53
37	0.60182	0.60414	0.60645	0.60876	0.61107	0.61337	0.61566	52
38	0.61566	0.61795	0.62024	0.62251	0.62479	0.62706	0.62932	51
39	0.62932	0.63158	0.63383	0.63608	0.63832	0.64056	0.64279	50
40	0.64279	0.64501	0.64723	0.64945	0.65166	0.65386	0.65606	49
41	0.65606	0.65825	0.66044	0.66262	0.66480	0.66697	0.66913	48
42	0.66913	0.67129	0.67344	0.67559	0.67773	0.67987	0.68200	47
43	0.68200	0.68412	0.68624	0.68835	0.69046	0.69256	0.69466	46
44	0.69466	0.69675	0.69883	0.70091	0.70298	0.70505	0.70711	45
Sines	COSINES 60′	50′	40′	30′	20′	10′	0′	Degrees

Table 93 (*Concluded*)
Natural Sines and Cosines

Degrees	COSINES							Sines
	0′	10′	20′	30′	40′	50′	60′	
0	1.00000	1.00000	0.99998	0.99996	0.99993	0.99989	0.99985	89
1	0.99985	0.99979	0.99973	0.99966	0.99958	0.99949	0.99939	88
2	0.99939	0.99929	0.99917	0.99905	0.99892	0.99878	0.99863	87
3	0.99863	0.99847	0.99831	0.99813	0.99795	0.99776	0.99756	86
4	0.99756	0.99736	0.99714	0.99692	0.99668	0.99644	0.99619	85
5	0.99619	0.99594	0.99567	0.99540	0.99511	0.99482	0.99452	84
6	0.99452	0.99421	0.99390	0.99357	0.99324	0.99290	0.99255	83
7	0.99255	0.99219	0.99182	0.99144	0.99106	0.99067	0.99027	82
8	0.99027	0.98986	0.98944	0.98902	0.98858	0.98814	0.98769	81
9	0.98769	0.98723	0.98676	0.98629	0.98580	0.98531	0.98481	80
10	0.98481	0.98430	0.98378	0.98325	0.98272	0.98218	0.98163	79
11	0.98163	0.98107	0.98050	0.97992	0.97934	0.97875	0.97815	78
12	0.97815	0.97754	0.97692	0.97630	0.97566	0.97502	0.97437	77
13	0.97437	0.97371	0.97304	0.97237	0.97169	0.97100	0.97030	76
14	0.97030	0.96959	0.96887	0.96815	0.96742	0.96667	0.96593	75
15	0.96593	0.96517	0.96440	0.96363	0.96285	0.96206	0.96126	74
16	0.96126	0.96046	0.95964	0.95882	0.95799	0.95715	0.95630	73
17	0.95630	0.95545	0.95459	0.95372	0.95284	0.95195	0.95106	72
18	0.95106	0.95015	0.94924	0.94832	0.94740	0.94646	0.94552	71
19	0.94552	0.94457	0.94361	0.94264	0.94167	0.94068	0.93969	70
20	0.93969	0.93869	0.93769	0.93667	0.93565	0.93462	0.93358	69
21	0.93358	0.93253	0.93148	0.93042	0.92935	0.92827	0.92718	68
22	0.92718	0.92609	0.92499	0.92388	0.92276	0.92164	0.92050	67
23	0.92050	0.91936	0.91822	0.91706	0.91590	0.91472	0.91355	66
24	0.91355	0.91236	0.91116	0.90996	0.90875	0.90753	0.90631	65
25	0.90631	0.90507	0.90383	0.90259	0.90133	0.90007	0.89879	64
26	0.89879	0.89752	0.89623	0.89493	0.89363	0.89232	0.89101	63
27	0.89101	0.88968	0.88835	0.88701	0.88566	0.88431	0.88295	62
28	0.88295	0.88158	0.88020	0.87882	0.87743	0.87603	0.87462	61
29	0.87462	0.87321	0.87178	0.87036	0.86892	0.86748	0.86603	60
30	0.86603	0.86457	0.86310	0.86163	0.86015	0.85866	0.85717	59
31	0.85717	0.85567	0.85416	0.85264	0.85112	0.84959	0.84805	58
32	0.84805	0.84650	0.84495	0.84339	0.84182	0.84025	0.83867	57
33	0.83867	0.83708	0.83549	0.83389	0.83228	0.83066	0.82904	56
34	0.82904	0.82741	0.82577	0.82413	0.82248	0.82082	0.81915	55
35	0.81915	0.81748	0.81580	0.81412	0.81242	0.81072	0.80902	54
36	0.80902	0.80730	0.80558	0.80386	0.80212	0.80038	0.79864	53
37	0.79864	0.79688	0.79512	0.79335	0.79158	0.78980	0.78801	52
38	0.78801	0.78622	0.78442	0.78261	0.78079	0.77897	0.77715	51
39	0.77715	0.77531	0.77347	0.77162	0.76977	0.76791	0.76604	50
40	0.76604	0.76417	0.76229	0.76041	0.75851	0.75661	0.75471	49
41	0.75471	0.75280	0.75088	0.74896	0.74703	0.74509	0.74314	48
42	0.74314	0.74120	0.73924	0.73728	0.73531	0.73333	0.73135	47
43	0.73135	0.72937	0.72737	0.72537	0.72337	0.72136	0.71934	46
44	0.71934	0.71732	0.71529	0.71325	0.71121	0.70916	0.70711	45
Cosines	60′	50′	40′	30′	20′	10′	0′	Degrees
	SINES							

TABLE 94.—NATURAL TANGENTS AND COTANGENTS

Degrees	0′	10′	20′	30′	40′	50′	60′	Co-tangents
	TANGENTS							
0	0.00000	0.00291	0.00582	0.00873	0.01164	0.01455	0.01746	89
1	0.01746	0.02036	0.02328	0.02619	0.02910	0.03201	0.03492	88
2	0.03492	0.03783	0.04075	0.04366	0.04658	0.04949	0.05241	87
3	0.05241	0.05533	0.05824	0.06116	0.06408	0.06700	0.06993	86
4	0.06993	0.07285	0.07578	0.07870	0.08163	0.08456	0.08749	85
5	0.08749	0.09042	0.09335	0.09629	0.09923	0.10216	0.10510	84
6	0.10510	0.10805	0.11099	0.11394	0.11688	0.11983	0.12278	83
7	0.12278	0.12574	0.12869	0.13165	0.13461	0.13758	0.14054	82
8	0.14054	0.14351	0.14648	0.14945	0.15243	0.15540	0.15838	81
9	0.15838	0.16137	0.16435	0.16734	0.17033	0.17333	0.17633	80
10	0.17633	0.17933	0.18233	0.18534	0.18835	0.19136	0.19438	79
11	0.19438	0.19740	0.20042	0.20345	0.20648	0.20952	0.21256	78
12	0.21256	0.21560	0.21864	0.22169	0.22475	0.22781	0.23087	77
13	0.23087	0.23393	0.23700	0.24008	0.24316	0.24624	0.24933	76
14	0.24933	0.25242	0.25552	0.25862	0.26172	0.26483	0.26795	75
15	0.26795	0.27107	0.27419	0.27732	0.28046	0.28360	0.28675	74
16	0.28675	0.28990	0.29305	0.29621	0.29938	0.30255	0.30573	73
17	0.30573	0.30891	0.31210	0.31530	0.31850	0.32171	0.32492	72
18	0.32492	0.32814	0.33136	0.33460	0.33783	0.34108	0.34433	71
19	0.34433	0.34758	0.35085	0.35412	0.35740	0.36068	0.36397	70
20	0.36397	0.36727	0.37057	0.37388	0.37720	0.38053	0.38386	69
21	0.38386	0.38721	0.39055	0.39391	0.39727	0.40065	0.40403	68
22	0.40403	0.40741	0.41081	0.41421	0.41763	0.42105	0.42447	67
23	0.42447	0.42791	0.43136	0.43481	0.43828	0.44175	0.44523	66
24	0.44523	0.44872	0.45222	0.45573	0.45924	0.46277	0.46631	65
25	0.46631	0.46985	0.47341	0.47698	0.48055	0.48414	0.48773	64
26	0.48773	0.49134	0.49495	0.49858	0.50222	0.50587	0.50953	63
27	0.50953	0.51320	0.51688	0.52057	0.52427	0.52798	0.53171	62
28	0.53171	0.53545	0.53920	0.54296	0.54674	0.55051	0.55431	61
29	0.55431	0.55812	0.56194	0.56577	0.56962	0.57348	0.57735	60
30	0.57735	0.58124	0.58513	0.58905	0.59297	0.59691	0.60086	59
31	0.60086	0.60483	0.60881	0.61280	0.61681	0.62083	0.62487	58
32	0.62487	0.62892	0.63299	0.63707	0.64117	0.64528	0.64941	57
33	0.64941	0.65355	0.65771	0.66189	0.66608	0.67028	0.67451	56
34	0.67451	0.67875	0.68301	0.68728	0.69157	0.69588	0.70021	55
35	0.70021	0.70455	0.70891	0.71329	0.71769	0.72211	0.72654	54
36	0.72654	0.73100	0.73547	0.73996	0.74447	0.74900	0.75355	53
37	0.75355	0.75812	0.76272	0.76733	0.77196	0.77661	0.78129	52
38	0.78129	0.78598	0.79070	0.79544	0.80020	0.80498	0.80978	51
39	0.80978	0.81461	0.81946	0.82434	0.82923	0.83415	0.83910	50
40	0.83910	0.84407	0.84906	0.85408	0.85912	0.86419	0.86929	49
41	0.86929	0.87441	0.87955	0.88473	0.88992	0.89515	0.90040	48
42	0.90040	0.90569	0.91099	0.91633	0.92170	0.92709	0.93252	47
43	0.93252	0.93797	0.94345	0.94896	0.95451	0.96008	0.96569	46
44	0.96569	0.97133	0.97700	0.98270	0.98843	0.99420	1.00000	45
Tangents	60′	50′	40′	30′	20′	10′	0′	Degrees
	COTANGENTS							

TABLE 94 (*Concluded*)

NATURAL TANGENTS AND COTANGENTS

Degrees	COTANGENTS							Tangents
	0′	10′	20′	30′	40′	50′	60′	
0	∞	343.77371	171.88540	114.58865	85.93979	68.75009	57.28996	89
1	57.28996	49.10388	42.96408	38.18846	34.36777	31.24158	28.63625	88
2	28.63625	26.43160	24.54176	22.90377	21.47040	20.20555	19.08114	87
3	19.08114	18.07498	17.16934	16.34986	15.60478	14.92442	14.30067	86
4	14.30067	13.72674	13.19688	12.70621	12.25051	11.82617	11.43005	85
5	11.43005	11.05943	10.71191	10.38540	10.07803	9.78817	9.51436	84
6	9.51436	9.25530	9.00983	8.77689	8.55555	8.34496	8.14435	83
7	8.14435	7.95302	7.77035	7.59575	7.42871	7.26873	7.11537	82
8	7.11537	6.96823	6.82694	6.69116	6.56055	6.43484	6.31375	81
9	6.31375	6.19703	6.08444	5.97576	5.87080	5.76937	5.67128	80
10	5.67128	5.57638	5.48451	5.39552	5.30928	5.22566	5.14455	79
11	5.14455	5.06584	4.98940	4.91516	4.84300	4.77286	4.70463	78
12	4.70463	4.63825	4.57363	4.51071	4.44942	4.38969	4.33148	77
13	4.33148	4.27471	4.21933	4.16530	4.11256	4.06107	4.01078	76
14	4.01078	3.96165	3.91364	3.86671	3.82083	3.77595	3.73205	75
15	3.73205	3.68909	3.64705	3.60588	3.56557	3.52609	3.48741	74
16	3.48741	3.44951	3.41236	3.37594	3.34023	3.30521	3.27085	73
17	3.27085	3.23714	3.20406	3.17159	3.13972	3.10842	3.07768	72
18	3.07768	3.04749	3.01783	2.98869	2.96004	2.93189	2.90421	71
19	2.90421	2.87700	2.85023	2.82391	2.79802	2.77254	2.74748	70
20	2.74748	2.72281	2.69853	2.67462	2.65109	2.62791	2.60509	69
21	2.60509	2.58261	2.56046	2.53865	2.51715	2.49597	2.47509	68
22	2.47509	2.45451	2.43422	2.41421	2.39449	2.37504	2.35585	67
23	2.35585	2.33693	2.31826	2.29984	2.28167	2.26374	2.24604	66
24	2.24604	2.22857	2.21132	2.19430	2.17749	2.16090	2.14451	65
25	2.14451	2.12832	2.11233	2.09654	2.08094	2.06553	2.05030	64
26	2.05030	2.03526	2.02039	2.00569	1.99116	1.97680	1.96261	63
27	1.96261	1.94858	1.93470	1.92098	1.90741	1.89400	1.88073	62
28	1.88073	1.86760	1.85462	1.84177	1.82907	1.81649	1.80405	61
29	1.80405	1.79174	1.77955	1.76749	1.75556	1.74375	1.73205	60
30	1.73205	1.72047	1.70901	1.69766	1.68643	1.67530	1.66428	59
31	1.66428	1.65337	1.64256	1.63185	1.62125	1.61074	1.60033	58
32	1.60033	1.59002	1.57981	1.56969	1.55966	1.54972	1.53987	57
33	1.53987	1.53010	1.52043	1.51084	1.50133	1.49190	1.48256	56
34	1.48256	1.47330	1.46411	1.45501	1.44598	1.43703	1.42815	55
35	1.42815	1.41934	1.41061	1.40195	1.39336	1.38484	1.37638	54
36	1.37638	1.36800	1.35968	1.35142	1.34323	1.33511	1.32704	53
37	1.32704	1.31904	1.31110	1.30323	1.29541	1.28764	1.27994	52
38	1.27994	1.27230	1.26471	1.25717	1.24969	1.24227	1.23490	51
39	1.23490	1.22758	1.22031	1.21310	1.20593	1.19882	1.19175	50
40	1.19175	1.18474	1.17777	1.17085	1.16398	1.15715	1.15037	49
41	1.15037	1.14363	1.13694	1.13029	1.12369	1.11713	1.11061	48
42	1.11061	1.10414	1.09770	1.09131	1.08496	1.07864	1.07237	47
43	1.07237	1.06613	1.05994	1.05378	1.04766	1.04158	1.03553	46
44	1.03553	1.02952	1.02355	1.01761	1.01170	1.00583	1.00000	45
Co-tangents	60′	50′	40′	30′	20′	10′	0′	Degrees
	TANGENTS							

TABLE 95.—NATURAL SECANTS AND COSECANTS

Degrees	SECANTS 0′	10′	20′	30′	40′	50′	60′	Cosecants
0	1.00000	1.00000	1.00002	1.00004	1.00007	1.00011	1.00015	89
1	1.00015	1.00021	1.00027	1.00034	1.00042	1.00051	1.00061	88
2	1.00061	1.00072	1.00083	1.00095	1.00108	1.00122	1.00137	87
3	1.00137	1.00153	1.00169	1.00187	1.00205	1.00224	1.00244	86
4	1.00244	1.00265	1.00287	1.00309	1.00333	1.00357	1.00382	85
5	1.00382	1.00408	1.00435	1.00463	1.00491	1.00521	1.00551	84
6	1.00551	1.00582	1.00614	1.00647	1.00681	1.00715	1.00751	83
7	1.00751	1.00787	1.00825	1.00863	1.00902	1.00942	1.00983	82
8	1.00983	1.01024	1.01067	1.01111	1.01155	1.01200	1.01247	81
9	1.01247	1.01294	1.01342	1.01391	1.01440	1.01491	1.01543	80
10	1.01543	1.01595	1.01649	1.01703	1.01758	1.01815	1.01872	79
11	1.01872	1.01930	1.01989	1.02049	1.02110	1.02171	1.02234	78
12	1.02234	1.02298	1.02362	1.02428	1.02494	1.02562	1.02630	77
13	1.02630	1.02700	1.02770	1.02842	1.02914	1.02987	1.03061	76
14	1.03061	1.03137	1.03213	1.03290	1.03368	1.03447	1.03528	75
15	1.03528	1.03609	1.03691	1.03774	1.03858	1.03944	1.04030	74
16	1.04030	1.04117	1.04206	1.04295	1.04385	1.04477	1.04569	73
17	1.04569	1.04663	1.04757	1.04853	1.04950	1.05047	1.05146	72
18	1.05146	1.05246	1.05347	1.05449	1.05552	1.05657	1.05762	71
19	1.05762	1.05869	1.05976	1.06085	1.06195	1.06306	1.06418	70
20	1.06418	1.06531	1.06645	1.06761	1.06878	1.06995	1.07115	69
21	1.07115	1.07235	1.07356	1.07479	1.07602	1.07727	1.07853	68
22	1.07853	1.07981	1.08109	1.08239	1.08370	1.08503	1.08636	67
23	1.08636	1.08771	1.08907	1.09044	1.09183	1.09323	1.09464	66
24	1.09464	1.09606	1.09750	1.09895	1.10041	1.10189	1.10338	65
25	1.10338	1.10488	1.10640	1.10793	1.10947	1.11103	1.11260	64
26	1.11260	1.11419	1.11579	1.11740	1.11903	1.12067	1.12233	63
27	1.12233	1.12400	1.12568	1.12738	1.12910	1.13083	1.13257	62
28	1.13257	1.13433	1.13610	1.13789	1.13970	1.14152	1.14335	61
29	1.14335	1.14521	1.14707	1.14896	1.15085	1.15277	1.15470	60
30	1.15470	1.15665	1.15861	1.16059	1.16259	1.16460	1.16663	59
31	1.16663	1.16868	1.17075	1.17283	1.17493	1.17704	1.17918	58
32	1.17918	1.18133	1.18350	1.18569	1.18790	1.19012	1.19236	57
33	1.19236	1.19463	1.19691	1.19920	1.20152	1.20386	1.20622	56
34	1.20622	1.20859	1.21099	1.21341	1.21584	1.21830	1.22077	55
35	1.22077	1.22327	1.22579	1.22833	1.23089	1.23347	1.23607	54
36	1.23607	1.23869	1.24134	1.24400	1.24669	1.24940	1.25214	53
37	1.25214	1.25489	1.25767	1.26047	1.26330	1.26615	1.26902	52
38	1.26902	1.27191	1.27483	1.27778	1.28075	1.28374	1.28676	51
39	1.28676	1.28980	1.29287	1.29597	1.29909	1.30223	1.30541	50
40	1.30541	1.30861	1.31183	1.31509	1.31837	1.32168	1.32501	49
41	1.32501	1.32838	1.33177	1.33519	1.33864	1.34212	1.34563	48
42	1.34563	1.34917	1.35274	1.35634	1.35997	1.36363	1.36733	47
43	1.36733	1.37105	1.37481	1.37860	1.38242	1.38628	1.39016	46
44	1.39016	1.39409	1.39804	1.40203	1.40606	1.41012	1.41421	45
Secants	COSECANTS 60′	50′	40′	30′	20′	10′	0′	Degrees

Table 95 (*Concluded*)
Natural Secants and Cosecants

Degrees	COSECANTS							Secants
	0′	10′	20′	30′	40′	50′	60′	
0	∞	343.77516	171.88831	114.59301	85.94561	68.75736	57.29869	89
1	57.29869	49.11406	42.97571	38.20155	34.38232	31.25758	28.65371	88
2	28.65371	26.45051	24.56212	22.92559	21.49368	20.23028	19.10732	87
3	19.10732	18.10262	17.19843	16.38041	15.63679	14.95788	14.33559	86
4	14.33559	13.76312	13.23472	12.74550	12.29125	11.86837	11.47371	85
5	11.47371	11.10455	10.75849	10.43343	10.12752	9.83912	9.56677	84
6	9.56677	9.30917	9.06515	8.83367	8.61379	8.40466	8.20551	83
7	8.20551	8.01565	7.83443	7.66130	7.49571	7.33719	7.18530	82
8	7.18530	7.03962	6.89979	6.76547	6.63633	6.51208	6.39245	81
9	6.39245	6.27719	6.16607	6.05886	5.95536	5.85539	5.75877	80
10	5.75877	5.66533	5.57493	5.48740	5.40263	5.32049	5.24084	79
11	5.24084	5.16359	5.08863	5.01585	4.94517	4.87649	4.80973	78
12	4.80973	4.74482	4.68167	4.62023	4.56041	4.50216	4.44541	77
13	4.44541	4.39012	4.33622	4.28366	4.23239	4.18238	4.13357	76
14	4.13357	4.08591	4.03938	3.99393	3.94952	3.90613	3.86370	75
15	3.86370	3.82223	3.78166	3.74198	3.70315	3.66515	3.62796	74
16	3.62796	3.59154	3.55587	3.52094	3.48671	3.45317	3.42030	73
17	3.42030	3.38808	3.35649	3.32551	3.29512	3.26531	3.23607	72
18	3.23607	3.20737	3.17920	3.15155	3.12440	3.09774	3.07155	71
19	3.07155	3.04584	3.02057	2.99574	2.97135	2.94737	2.92380	70
20	2.92380	2.90063	2.87785	2.85545	2.83342	2.81175	2.79043	69
21	2.79043	2.76945	2.74881	2.72850	2.70851	2.68884	2.66947	68
22	2.66947	2.65040	2.63162	2.61313	2.59491	2.57698	2.55930	67
23	2.55930	2.54190	2.52474	2.50784	2.49119	2.47477	2.45859	66
24	2.45859	2.44264	2.42692	2.41142	2.39614	2.38107	2.36620	65
25	2.36620	2.35154	2.33708	2.32282	2.30875	2.29487	2.28117	64
26	2.28117	2.26766	2.25432	2.24116	2.22817	2.21535	2.20269	63
27	2.20269	2.19019	2.17786	2.16568	2.15366	2.14178	2.13005	62
28	2.13005	2.11847	2.10704	2.09574	2.08458	2.07356	2.06267	61
29	2.06267	2.05191	2.04128	2.03077	2.02039	2.01014	2.00000	60
30	2.00000	1.98998	1.98008	1.97029	1.96062	1.95106	1.94160	59
31	1.94160	1.93226	1.92302	1.91388	1.90485	1.89591	1.88708	58
32	1.88708	1.87834	1.86970	1.86116	1.85271	1.84435	1.83608	57
33	1.83608	1.82790	1.81981	1.81180	1.80388	1.79604	1.78829	56
34	1.78829	1.78062	1.77303	1.76552	1.75808	1.75073	1.74345	55
35	1.74345	1.73624	1.72911	1.72205	1.71506	1.70815	1.70130	54
36	1.70130	1.69452	1.68782	1.68117	1.67460	1.66809	1.66164	53
37	1.66164	1.65526	1.64894	1.64268	1.63648	1.63035	1.62427	52
38	1.62427	1.61825	1.61229	1.60639	1.60054	1.59475	1.58902	51
39	1.58902	1.58333	1.57771	1.57213	1.56661	1.56114	1.55572	50
40	1.55572	1.55036	1.54504	1.53977	1.53455	1.52938	1.52425	49
41	1.52425	1.51918	1.51415	1.50916	1.50422	1.49933	1.49448	48
42	1.49448	1.48967	1.48491	1.48019	1.47551	1.47087	1.46628	47
43	1.46628	1.46173	1.45721	1.45274	1.44831	1.44391	1.43956	46
44	1.43956	1.43524	1.43096	1.42672	1.42251	1.41835	1.41421	45
Cosecants	60′	50′	40′	30′	20′	10′	0′	Degrees
	SECANTS							

TABLE 96.—SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS, RECIPROCALS

Num.	Square	Cube	Square root	Cube root	Reciprocal
1	1	1	1.0000000	1.0000000	1.000000000
2	4	8	1.4142136	1.2599210	0.500000000
3	9	27	1.7320508	1.4422496	.333333333
4	16	64	2.0000000	1.5874011	.250000000
5	25	125	2.2360680	1.7099759	.200000000
6	36	216	2.4494897	1.8171206	.166666667
7	49	343	2.6457513	1.9129312	.142857143
8	64	512	2.8284271	2.0000000	.125000000
9	81	729	3.0000000	2.0800837	.111111111
10	1 00	1 000	3.1622777	2.1544347	.100000000
11	1 21	1 331	3.3166248	2.2239801	.090909091
12	1 44	1 728	3.4641016	2.2894286	.083333333
13	1 69	2 197	3.6055513	2.3513347	.076923077
14	1 96	2 744	3.7416574	2.4101422	.071428571
15	2 25	3 375	3.8729833	2.4662121	.066666667
16	2 56	4 096	4.0000000	2.5198421	.062500000
17	2 89	4 913	4.1231056	2.5712816	.058823529
18	3 24	5 832	4.2426407	2.6207414	.055555556
19	3 61	6 859	4.3588989	2.6684016	.052631579
20	4 00	8 000	4.4721360	2.7144177	.050000000
21	4 41	9 261	4.5825757	2.7589243	.047619048
22	4 84	10 648	4.6904158	2.8020393	.045454545
23	5 29	12 167	4.7958315	2.8438670	.043478261
24	5 76	13 824	4.8989795	2.8844991	.041666667
25	6 25	15 625	5.0000000	2.9240177	.040000000
26	6 76	17 576	5.0990195	2.9624960	.038461538
27	7 29	19 683	5.1961524	3.0000000	.037037037
28	7 84	21 952	5.2915026	3.0365889	.035714286
29	8 41	24 389	5.3851648	3.0723168	.034482759
30	9 00	27 000	5.4772256	3.1072325	.033333333
31	9 61	29 791	5.5677644	3.1413806	.032258065
32	10 24	32 768	5.6568542	3.1748021	.031250000
33	10 89	35 937	5.7445626	3.2075343	.030303030
34	11 56	39 304	5.8309519	3.2396118	.029411765
35	12 25	42 875	5.9160798	3.2710663	.028571429
36	12 96	46 656	6.0000000	3.3019272	.027777778
37	13 69	50 653	6.0827625	3.3322218	.027027027
38	14 44	54 872	6.1644140	3.3619754	.026315789
39	15 21	59 319	6.2449980	3.3912114	.025641026
40	16 00	64 000	6.3245553	3.4199519	.025000000
41	16 81	68 921	6.4031242	3.4482172	.024390244
42	17 64	74 088	6.4807407	3.4760266	.023809524
43	18 49	79 507	6.5574385	3.5033981	.023255814
44	19 36	85 184	6.6332496	3.5303483	.022727273
45	20 25	91 125	6.7082039	3.5568933	.022222222
46	21 16	97 336	6.7823300	3.5830479	.021739130
47	22 09	103 823	6.8556546	3.6088261	.021276596
48	23 04	110 592	6.9282032	3.6342411	.020833333
49	24 01	117 649	7.0000000	3.6593057	.020408163
50	25 00	125 000	7.0710678	3.6840314	.020000000

Table 96 (*Continued*)

Squares, Cubes, Square Roots, Cube Roots, Reciprocals

Num.	Square	Cube	Square root	Cube root	Reciprocal
51	26 01	132 651	7.1414284	3.7084298	.019607843
52	27 04	140 608	7.2111026	3.7325111	.019230769
53	28 09	148 877	7.2801099	3.7562858	.018867925
54	29 16	157 464	7.3484692	3.7797631	.018518519
55	30 25	166 375	7.4161985	3.8029525	.018181818
56	31 36	175 616	7.4833148	3.8258624	.017857143
57	32 49	185 193	7.5498344	3.8485011	.017543860
58	33 64	195 112	7.6157731	3.8708766	.017241379
59	34 81	205 379	7.6811457	3.8929965	.016949153
60	36 00	216 000	7.7459667	3.9148676	.016666667
61	37 21	226 981	7.8102497	3.9364972	.016393443
62	38 44	238 328	7.8740079	3.9578915	.016129032
63	39 69	250 047	7.9372539	3.9790571	.015873016
64	40 96	262 144	8.0000000	4.0000000	.015625000
65	42 25	274 625	8.0622577	4.0207256	.015384615
66	43 56	287 496	8.1240384	4.0412401	.015151515
67	44 89	300 763	8.1853528	4.0615480	.014925373
68	46 24	314 432	8.2462113	4.0816551	.014705882
69	47 61	328 509	8.3066239	4.1015661	.014492754
70	49 00	343 000	8.3666003	4.1212853	.014285714
71	50 41	357 911	8.4261498	4.1408178	.014084507
72	51 84	373 248	8.4852814	4.1601676	.013888889
73	53 29	389 017	8.5440037	4.1793392	.013698630
74	54 76	405 224	8.6023253	4.1983364	.013513514
75	56 25	421 875	8.6602540	4.2171633	.013333333
76	57 76	438 976	8.7177979	4.2358236	.013157895
77	59 29	456 533	8.7749644	4.2543210	.012987013
78	60 84	474 552	8.8317609	4.2726586	.012820513
79	62 41	493 039	8.8881944	4.2908404	.012658228
80	64 00	512 000	8.9442719	4.3088695	.012500000
81	65 61	531 441	9.0000000	4.3267487	.012345679
82	67 24	551 368	9.0553851	4.3444815	.012195122
83	68 89	571 787	9.1104336	4.3620707	.012048193
84	70 56	592 704	9.1651514	4.3795191	.011904762
85	72 25	614 125	9.2195445	4.3968296	.011764706
86	73 96	636 056	9.2736185	4.4140049	.011627907
87	75 69	658 503	9.3273791	4.4310476	.011494253
88	77 44	681 472	9.3808315	4.4479602	.011363636
89	79 21	704 969	9.4339811	4.4647451	.011235955
90	81 00	729 000	9.4868330	4.4814047	.011111111
91	82 81	753 571	9.5393920	4.4979414	.010989011
92	84 64	778 688	9.5916630	4.5143574	.010869565
93	86 49	804 357	9.6436508	4.5306549	.010752688
94	88 36	830 584	9.6953597	4.5468359	.010638298
95	90 25	857 375	9.7467943	4.5629026	.010526316
96	92 16	884 736	9.7979590	4.5788570	.010416667
97	94 09	912 673	9.8488578	4.5947009	.010309278
98	96 04	941 192	9.8994949	4.6104363	.010204082
99	98 01	970 299	9.9498744	4.6260650	.010101010
100	1 00 00	1 000 000	10.0000000	4.6415888	.010000000

TABLE 96 (*Continued*)

SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS, RECIPROCALS

Num.	Square	Cube	Square root	Cube root	Reciprocal
101	1 02 01	1 030 301	10.0498756	4.6570095	.009900990
102	1 04 04	1 061 208	10.0995049	4.6723287	.009803922
103	1 06 09	1 092 727	10.1488916	4.6875482	.009708738
104	1 08 16	1 124 864	10.1980390	4.7026694	.009615385
105	1 10 25	1 157 625	10.2469508	4.7176940	.009523810
106	1 12 36	1 191 016	10.2956301	4.7326235	.009433962
107	1 14 49	1 225 043	10.3440804	4.7474594	.009345794
108	1 16 64	1 259 712	10.3923048	4.7622032	.009259259
109	1 18 81	1 295 029	10.4403065	4.7768562	.009174312
110	1 21 00	1 331 000	10.4880885	4.7914199	.009090909
111	1 23 21	1 367 631	10.5356538	4.8058955	.009009009
112	1 25 44	1 404 928	10.5830052	4.8202845	.008928571
113	1 27 69	1 442 897	10.6301458	4.8345881	.008849558
114	1 29 96	1 481 544	10.6770783	4.8488076	.008771930
115	1 32 25	1 520 875	10.7238053	4.8629442	.008695652
116	1 34 56	1 560 896	10.7703296	4.8769990	.008620690
117	1 36 89	1 601 613	10.8166538	4.8909732	.008547009
118	1 39 24	1 643 032	10.8627805	4.9048681	.008474576
119	1 41 61	1 685 159	10.9087121	4.9186847	.008403361
120	1 44 00	1 728 000	10.9544512	4.9324242	.008333333
121	1 46 41	1 771 561	11.0000000	4.9460874	.008264463
122	1 48 84	1 815 848	11.0453610	4.9596757	.008196721
123	1 51 29	1 860 867	11.0905365	4.9731898	.008130081
124	1 53 76	1 906 624	11.1355287	4.9866310	.008064516
125	1 56 25	1 953 125	11.1803399	5.0000000	.008000000
126	1 58 76	2 000 376	11.2249722	5.0132979	.007936508
127	1 61 29	2 048 383	11.2694277	5.0265257	.007874016
128	1 63 84	2 097 152	11.3137085	5.0396842	.007812500
129	1 66 41	2 146 689	11.3578167	5.0527743	.007751938
130	1 69 00	2 197 000	11.4017543	5.0657970	.007692308
131	1 71 61	2 248 091	11.4455231	5.0787531	.007633588
132	1 74 24	2 299 968	11.4891253	5.0916434	.007575758
133	1 76 89	2 352 637	11.5325626	5.1044687	.007518797
134	1 79 56	2 406 104	11.5758369	5.1172299	.007462687
135	1 82 25	2 460 375	11.6189500	5.1299278	.007407407
136	1 84 96	2 515 456	11.6619038	5.1425632	.007352941
137	1 87 69	2 571 353	11.7046999	5.1551367	.007299270
138	1 90 44	2 628 072	11.7473401	5.1676493	.007246377
139	1 93 21	2 685 619	11.7898261	5.1801015	.007194245
140	1 96 00	2 744 000	11.8321596	5.1924941	.007142857
141	1 98 81	2 803 221	11.8743422	5.2048279	.007092199
142	2 01 64	2 863 288	11.9163753	5.2171034	.007042254
143	2 04 49	2 924 207	11.9582607	5.2293215	.006993007
144	2 07 36	2 985 984	12.0000000	5.2414828	.006944444
145	2 10 25	3 048 625	12.0415946	5.2535879	.006896552
146	2 13 16	3 112 136	12.0830460	5.2656374	.006849315
147	2 16 09	3 176 523	12.1243557	5.2776321	.006802721
148	2 19 04	3 241 792	12.1655251	5.2895725	.006756757
149	2 22 01	3 307 949	12.2065556	5.3014592	.006711409
150	2 25 00	3 375 000	12.2474487	5.3132928	.006666667

TABLE 96 (*Continued*)

SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS, RECIPROCALS

Num.	Square	Cube	Square root	Cube root	Reciprocal
151	2 28 01	3 442 951	12.2882057	5.3250740	.006622517
152	2 31 04	3 511 808	12.3288280	5.3368033	.006578947
153	2 34 09	3 581 577	12.3693169	5.3484812	.006535948
154	2 37 16	3 652 264	12.4096736	5.3601084	.006493506
155	2 40 25	3 723 875	12.4498996	5.3716854	.006451613
156	2 43 36	3 796 416	12.4899960	5.3832126	.006410256
157	2 46 49	3 869 893	12.5299641	5.3946907	.006369427
158	2 49 64	3 944 312	12.5698051	5.4061202	.006329114
159	2 52 81	4 019 679	12.6095202	5.4175015	.006289308
160	2 56 00	4 096 000	12.6491106	5.4288352	.006250000
161	2 59 21	4 173 281	12.6885775	5.4401218	.006211180
162	2 62 44	4 251 528	12.7279221	5.4513618	.006172840
163	2 65 69	4 330 747	12.7671453	5.4625556	.006134969
164	2 68 96	4 410 944	12.8062485	5.4737037	.006097561
165	2 72 25	4 492 125	12.8452326	5.4848066	.006060606
166	2 75 56	4 574 296	12.8840987	5.4958647	.006024096
167	2 78 89	4 657 463	12.9228480	5.5068784	.005988024
168	2 82 24	4 741 632	12.9614814	5.5178484	.005952381
169	2 85 61	4 826 809	13.0000000	5.5287748	.005917160
170	2 89 00	4 913 000	13.0384048	5.5396583	.005882353
171	2 92 41	5 000 211	13.0766968	5.5504991	.005847953
172	2 95 84	5 088 448	13.1148770	5.5612978	.005813953
173	2 99 29	5 177 717	13.1529464	5.5720546	.005780347
174	3 02 76	5 268 024	13.1909060	5.5827702	.005747126
175	3 06 25	5 359 375	13.2287566	5.5934447	.005714286
176	3 09 76	5 451 776	13.2664992	5.6040787	.005681818
177	3 13 29	5 545 233	13.3041347	5.6146724	.005649718
178	3 16 84	5 639 752	13.3416641	5.6252263	.005617978
179	3 20 41	5 735 339	13.3790882	5.6357408	.005586592
180	3 24 00	5 832 000	13.4164079	5.6462162	.005555556
181	3 27 61	5 929 741	13.4536240	5.6566528	.005524862
182	3 31 24	6 028 568	13.4907376	5.6670511	.005494505
183	3 34 89	6 128 487	13.5277493	5.6774114	.005464481
184	3 38 56	6 229 504	13.5646600	5.6877340	.005434783
185	3 42 25	6 331 625	13.6014705	5.6980192	.005405405
186	3 45 96	6 434 856	13.6381817	5.7082675	.005376344
187	3 49 69	6 539 203	13.6747943	5.7184791	.005347594
188	3 53 44	6 644 672	13.7113092	5.7286543	.005319149
189	3 57 21	6 751 269	13.7477271	5.7387936	.005291005
190	3 61 00	6 859 000	13.7840488	5.7488971	.005263158
191	3 64 81	6 967 871	13.8202750	5.7589652	.005235602
192	3 68 64	7 077 888	13.8564065	5.7689982	.005208333
193	3 72 49	7 189 057	13.8924440	5.7789966	.005181347
194	3 76 36	7 301 384	13.9283883	5.7889604	.005154639
195	3 80 25	7 414 875	13.9642400	5.7988900	.005128205
196	3 84 16	7 529 536	14.0000000	5.8087857	.005102041
197	3 88 09	7 645 373	14.0356688	5.8186479	.005076142
198	3 92 04	7 762 392	14.0712473	5.8284767	.005050505
199	3 96 01	7 880 599	14.1067360	5.8382725	.005025126
200	4 00 00	8 000 000	14.1421356	5.8480355	.005000000

TABLE 96 (*Continued*)

SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS, RECIPROCALS

Num.	Square	Cube	Square root	Cube root	Reciprocal
201	4 04 01	8 120 601	14.1774469	5.8577660	.004975124
202	4 08 04	8 242 408	14.2126704	5.8674643	.004950495
203	4 12 09	8 365 427	14.2478068	5.8771307	.004926108
204	4 16 16	8 489 664	14.2828569	5.8867653	.004901961
205	4 20 25	8 615 125	14.3178211	5.8963685	.004878049
206	4 24 36	8 741 816	14.3527001	5.9059406	.004854369
207	4 28 49	8 869 743	14.3874946	5.9154817	.004830918
208	4 32 64	8 998 912	14.4222051	5.9249921	.004807692
209	4 36 81	9 129 329	14.4568323	5.9344721	.004784689
210	4 41 00	9 261 000	14.4913767	5.9439220	.004761905
211	4 45 21	9 393 931	14.5258390	5.9533418	.004739336
212	4 49 44	9 528 128	14.5602198	5.9627320	.004716981
213	4 53 69	9 663 597	14.5945195	5.9720926	.004694836
214	4 57 96	9 800 344	14.6287388	5.9814240	.004672897
215	4 62 25	9 938 375	14.6628783	5.9907264	.004651163
216	4 66 56	10 077 696	14.6969385	6.0000000	.004629630
217	4 70 89	10 218 313	14.7309199	6.0092450	.004608295
218	4 75 24	10 360 232	14.7648231	6.0184617	.004587156
219	4 79 61	10 503 459	14.7986486	6.0276502	.004566210
220	4 84 00	10 648 000	14.8323970	6.0368107	.004545455
221	4 88 41	10 793 861	14.8660687	6.0459435	.004524887
222	4 92 84	10 941 048	14.8996644	6.0550489	.004504505
223	4 97 29	11 089 567	14.9331845	6.0641270	.004484305
224	5 01 76	11 239 424	14.9666295	6.0731779	.004464286
225	5 06 25	11 390 625	15.0000000	6.0822020	.004444444
226	5 10 76	11 543 176	15.0332964	6.0911994	.004424779
227	5 15 29	11 697 083	15.0665192	6.1001702	.004405286
228	5 19 84	11 852 352	15.0996689	6.1091147	.004385965
229	5 24 41	12 008 989	15.1327460	6.1180332	.004366812
230	5 29 00	12 167 000	15.1657509	6.1269257	.004347826
231	5 33 61	12 326 391	15.1986842	6.1357924	.004329004
232	5 38 24	12 487 168	15.2315462	6.1446337	.004310345
233	5 42 89	12 649 337	15.2643375	6.1534495	.004291845
234	5 47 56	12 812 904	15.2970585	6.1622401	.004273504
235	5 52 25	12 977 875	15.3297097	6.1710058	.004255319
236	5 56 96	13 144 256	15.3622915	6.1797466	.004237288
237	5 61 69	13 312 053	15.3948043	6.1884628	.004219409
238	5 66 44	13 481 272	15.4272486	6.1971544	.004201681
239	5 71 21	13 651 919	15.4596248	6.2058218	.004184100
240	5 76 00	13 824 000	15.4919334	6.2144650	.004166667
241	5 80 81	13 997 521	15.5241747	6.2230843	.004149378
242	5 85 64	14 172 488	15.5563492	6.2316797	.004132231
243	5 90 49	14 348 907	15.5884573	6.2402515	.004115226
244	5 95 36	14 526 784	15.6204994	6.2487998	.004098361
245	6 00 25	14 706 125	15.6524758	6.2573248	.004081633
246	6 05 16	14 886 936	15.6843871	6.2658266	.004065041
247	6 10 09	15 069 223	15.7162336	6.2743054	.004048583
248	6 15 04	15 252 992	15.7480157	6.2827613	.004032258
249	6 20 01	15 438 249	15.7797338	6.2911946	.004016064
250	6 25 00	15 625 000	15.8113883	6.2996053	.004000000

TABLE 96 (*Continued*)

SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS, RECIPROCALS

Num.	Square	Cube	Square root	Cube root	Reciprocal
251	6 30 01	15 813 251	15.8429795	6.3079935	.003984064
252	6 35 04	16 003 008	15.8745079	6.3163596	.003968254
253	6 40 09	16 194 277	15.9059737	6.3247035	.003952569
254	6 45 16	16 387 064	15.9373775	6.3330256	.003937008
255	6 50 25	16 581 375	15.9687194	6.3413257	.003921569
256	6 55 36	16 777 216	16.0000000	6.3496042	.003906250
257	6 60 49	16 974 593	16.0312195	6.3578611	.003891051
258	6 65 64	17 173 512	16.0623784	6.3660968	.003875969
259	6 70 81	17 373 979	16.0934769	6.3743111	.003861004
260	6 76 00	17 576 000	16.1245155	6.3825043	.003846154
261	6 81 21	17 779 581	16.1554944	6.3906765	.003831418
262	6 86 44	17 984 728	16.1864141	6.3988279	.003816794
263	6 91 69	18 191 447	16.2172747	6.4069585	.003802281
264	6 96 96	18 399 744	16.2480768	6.4150687	.003787879
265	7 02 25	18 609 625	16.2788206	6.4231583	.003773585
266	7 07 56	18 821 096	16.3095064	6.4312276	.003759398
267	7 12 89	19 034 163	16.3401346	6.4392767	.003745318
268	7 18 24	19 248 832	16.3707055	6.4473057	.003731343
269	7 23 61	19 465 109	16.4012195	6.4553148	.003717472
270	7 29 00	19 683 000	16.4316767	6.4633041	.003703704
271	7 34 41	19 902 511	16.4620776	6.4712736	.003690037
272	7 39 84	20 123 648	16.4924225	6.4792236	.003676471
273	7 45 29	20 346 417	16.5227116	6.4871541	.003663004
274	7 50 76	20 570 824	16.5529454	6.4950653	.003649635
275	7 56 25	20 796 875	16.5831240	6.5029572	.003636364
276	7 61 76	21 024 576	16.6132477	6.5108300	.003623188
277	7 67 29	21 253 933	16.6433170	6.5186839	.003610108
278	7 72 84	21 484 952	16.6733320	6.5265189	.003597122
279	7 78 41	21 717 639	16.7032931	6.5343351	.003584229
280	7 84 00	21 952 000	16.7332005	6.5421326	.003571429
281	7 89 61	22 188 041	16.7630546	6.5499116	.003558719
282	7 95 24	22 425 768	16.7928556	6.5576722	.003546099
283	8 00 89	22 665 187	16.8226038	6.5654144	.003533569
284	8 06 56	22 906 304	16.8522995	6.5731385	.003521127
285	8 12 25	23 149 125	16.8819430	6.5808443	.003508772
286	8 17 96	23 393 656	16.9115345	6.5885323	.003496503
287	8 23 69	23 639 903	16.9410743	6.5962023	.003484321
288	8 29 44	23 887 872	16.9705627	6.6038545	.003472222
289	8 35 21	24 137 569	17.0000000	6.6114890	.003460208
290	8 41 00	24 389 000	17.0293864	6.6191060	.003448276
291	8 46 81	24 642 171	17.0587221	6.6267054	.003436426
292	8 52 64	24 897 088	17.0880075	6.6342874	.003424658
293	8 58 49	25 153 757	17.1172428	6.6418522	.003412969
294	8 64 36	25 412 184	17.1464282	6.6493998	.003401361
295	8 70 25	25 672 375	17.1755640	6.6569302	.003389831
296	8 76 16	25 934 336	17.2046505	6.6644437	.003378378
297	8 82 09	26 198 073	17.2336879	6.6719403	.003367003
298	8 88 04	26 463 592	17.2626765	6.6794200	.003355705
299	8 94 01	26 730 899	17.2916165	6.6868831	.003344482
300	9 00 00	27 000 000	17.3205081	6.6943295	.003333333

TABLE 96 (*Continued*)

SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS, RECIPROCALS

Num.	Square	Cube	Square root	Cube root	Reciprocal
301	9 06 01	27 270 901	17.3493516	6.7017593	.003322259
302	9 12 04	27 543 608	17.3781472	6.7091729	.003311258
303	9 18 09	27 818 127	17.4068952	6.7165700	.003300330
304	9 24 16	28 094 464	17.4355958	6.7239508	.003289474
305	9 30 25	28 372 625	17.4642492	6.7313155	.003278689
306	9 36 36	28 652 616	17.4928557	6.7386641	.003267974
307	9 42 49	28 934 443	17.5214155	6.7459967	.003257329
308	9 48 64	29 218 112	17.5499288	6.7533134	.003246753
309	9 54 81	29 503 629	17.5783958	6.7606143	.003236246
310	9 61 00	29 791 000	17.6068169	6.7678995	.003225806
311	9 67 21	30 080 231	17.6351921	6.7751690	.003215434
312	9 73 44	30 371 328	17.6635217	6.7824229	.003205128
313	9 79 69	30 664 297	17.6918060	6.7896613	.003194888
314	9 85 96	30 959 144	17.7200451	6.7968844	.003184713
315	9 92 25	31 255 875	17.7482393	6.8040921	.003174603
316	9 98 56	31 554 496	17.7763888	6.8112847	.003164557
317	10 04 89	31 855 013	17.8044938	6.8184620	.003154574
318	10 11 24	32 157 432	17.8325545	6.8256242	.003144654
319	10 17 61	32 461 759	17.8605711	6.8327714	.003134796
320	10 24 00	32 768 000	17.8885438	6.8399037	.003125000
321	10 30 41	33 076 161	17.9164729	6.8470213	.003115265
322	10 36 84	33 386 248	17.9443584	6.8541240	.003105590
323	10 43 29	33 698 267	17.9722008	6.8612120	.003095975
324	10 49 76	34 012 224	18.0000000	6.8682855	.003086420
325	10 56 25	34 328 125	18.0277564	6.8753443	.003076923
326	10 62 76	34 645 976	18.0554701	6.8823888	.003067485
327	10 69 29	34 965 783	18.0831413	6.8894188	.003058104
328	10 75 84	35 287 552	18.1107703	6.8964345	.003048780
329	10 82 41	35 611 289	18.1383571	6.9034359	.003039514
330	10 89 00	35 937 000	18.1659021	6.9104232	.003030303
331	10 95 61	36 264 691	18.1934054	6.9173964	.003021148
332	11 02 24	36 594 368	18.2208672	6.9243556	.003012048
333	11 08 89	36 926 037	18.2482876	6.9313008	.003003003
334	11 15 56	37 259 704	18.2756669	6.9382321	.002994012
335	11 22 25	37 595 375	18.3030052	6.9451496	.002985075
336	11 28 96	37 933 056	18.3303028	6.9520533	.002976190
337	11 35 69	38 272 753	18.3575598	6.9589434	.002967359
338	11 42 44	38 614 472	18.3847763	6.9658198	.002958580
339	11 49 21	38 958 219	18.4119526	6.9726826	.002949853
340	11 56 00	39 304 000	18.4390889	6.9795321	.002941176
341	11 62 81	39 651 821	18.4661853	6.9863681	.002932551
342	11 69 64	40 001 688	18.4932420	6.9931906	.002923977
343	11 76 49	40 353 607	18.5202592	7.0000000	.002915452
344	11 83 36	40 707 584	18.5472370	7.0067962	.002906977
345	11 90 25	41 063 625	18.5741756	7.0135791	.002898551
346	11 97 16	41 421 736	18.6010752	7.0203490	.002890173
347	12 04 09	41 781 923	18.6279360	7.0271058	.002881844
348	12 11 04	42 144 192	18.6547581	7.0338497	.002873563
349	12 18 01	42 508 549	18.6815417	7.0405806	.002865330
350	12 25 00	42 875 000	18.7082869	7.0472987	.002857143

TABLE 96 (*Continued*)

SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS, RECIPROCALS

Num.	Square	Cube	Square root	Cube root	Reciprocal
351	12 32 01	43 243 551	18.7349940	7.0540041	.002849003
352	12 39 04	43 614 208	18.7616630	7.0606967	.002840909
353	12 46 09	43 986 977	18.7882942	7.0673767	.002832861
354	12 53 16	44 361 864	18.8148877	7.0740440	.002824859
355	12 60 25	44 738 875	18.8414437	7.0806988	.002816901
356	12 67 36	45 118 016	18.8679623	7.0873411	.002808989
357	12 74 49	45 499 293	18.8944436	7.0939709	.002801120
358	12 81 64	45 882 712	18.9208879	7.1005885	.002793296
359	12 88 81	46 268 279	18.9472953	7.1071937	.002785515
360	12 96 00	46 656 000	18.9736660	7.1137866	.002777778
361	13 03 21	47 045 881	19.0000000	7.1203674	.002770083
362	13 10 44	47 437 928	19.0262976	7.1269360	.002762431
363	13 17 69	47 832 147	19.0525589	7.1334925	.002754821
364	13 24 96	48 228 544	19.0787840	7.1400370	.002747253
365	13 32 25	48 627 125	19.1049732	7.1465695	.002739726
366	13 39 56	49 027 896	19.1311265	7.1530901	.002732240
367	13 46 89	49 430 863	19.1572441	7.1595988	.002724796
368	13 54 24	49 836 032	19.1833261	7.1660957	.002717391
369	13 61 61	50 243 409	19.2093727	7.1725809	.002710027
370	13 69 00	50 653 000	19.2353841	7.1790544	.002702703
371	13 76 41	51 064 811	19.2613603	7.1855162	.002695418
372	13 83 84	51 478 848	19.2873015	7.1919663	.002688172
373	13 91 29	51 895 117	19.3132079	7.1984050	.002680965
374	13 98 76	52 313 624	19.3390796	7.2048322	.002673797
375	14 06 25	52 734 375	19.3649167	7.2112479	.002666667
376	14 13 76	53 157 376	19.3907194	7.2176522	.002659574
377	14 21 29	53 582 633	19.4164878	7.2240450	.002652520
378	14 28 84	54 010 152	19.4422221	7.2304268	.002645503
379	14 36 41	54 439 939	19.4679223	7.2367972	.002638522
380	14 44 00	54 872 000	19.4935887	7.2431565	.002631579
381	14 51 61	55 306 341	19.5192213	7.2495045	.002624672
382	14 59 24	55 742 968	19.5448203	7.2558415	.002617801
383	14 66 89	56 181 887	19.5703858	7.2621675	.002610966
384	14 74 56	56 623 104	19.5959179	7.2684824	.002604167
385	14 82 25	57 066 625	19.6214169	7.2747864	.002597403
386	14 89 96	57 512 456	19.6468827	7.2810794	.002590674
387	14 97 69	57 960 603	19.6723156	7.2873617	.002583979
388	15 05 44	58 411 072	19.6977156	7.2936330	.002577320
389	15 13 21	58 863 869	19.7230829	7.2998936	.002570694
390	15 21 00	59 319 000	19.7484177	7.3061436	.002564103
391	15 28 81	59 776 471	19.7737199	7.3123828	.002557545
392	15 36 64	60 236 288	19.7989899	7.3186114	.002551020
393	15 44 49	60 698 457	19.8242276	7.3248295	.002544529
394	15 52 36	61 162 984	19.8494332	7.3310369	.002538071
395	15 60 25	61 629 875	19.8746069	7.3372339	.002531646
396	15 68 16	62 099 136	19.8997487	7.3434205	.002525253
397	15 76 09	62 570 773	19.9248588	7.3495966	.002518892
398	15 84 04	63 044 792	19.9499373	7.3557624	.002512563
399	15 92 01	63 521 199	19.9749844	7.3619178	.002506266
400	16 00 00	64 000 000	20.0000000	7.3680630	.002500000

TABLE 96 (*Continued*)

SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS, RECIPROCALS

Num.	Square	Cube	Square root	Cube root	Reciprocal
401	16 08 01	64 481 201	20.0249844	7.3741979	.002493766
402	16 16 04	64 964 808	20.0499377	7.3803227	.002487562
403	16 24 09	65 450 827	20.0748599	7.3864373	.002481390
404	16 32 16	65 939 264	20.0997512	7.3925418	.002475248
405	16 40 25	66 430 125	20.1246118	7.3986363	.002469136
406	16 48 36	66 923 416	20.1494417	7.4047206	.002463054
407	16 56 49	67 419 143	20.1742410	7.4107950	.002457002
408	16 64 64	67 917 312	20.1990099	7.4168595	.002450980
409	16 72 81	68 417 929	20.2237484	7.4229142	.002444988
410	16 81 00	68 921 000	20.2484567	7.4289589	.002439024
411	16 89 21	69 426 531	20.2731349	7.4349938	.002433090
412	16 97 44	69 934 528	20.2977831	7.4410189	.002427184
413	17 05 69	70 444 997	20.3224014	7.4470342	.002421308
414	17 13 96	70 957 944	20.3469899	7.4530399	.002415459
415	17 22 25	71 473 375	20.3715488	7.4590359	.002409639
416	17 30 56	71 991 296	20.3960781	7.4650223	.002403846
417	17 38 89	72 511 713	20.4205779	7.4709991	.002398082
418	17 47 24	73 034 632	20.4450483	7.4769664	.002392344
419	17 55 61	73 560 059	20.4694895	7.4829242	.002386635
420	17 64 00	74 088 000	20.4939015	7.4888724	.002380952
421	17 72 41	74 618 461	20.5182845	7.4948113	.002375297
422	17 80 84	75 151 448	20.5426386	7.5007406	.002369668
423	17 89 29	75 686 967	20.5669638	7.5066607	.002364066
424	17 97 76	76 225 024	20.5912603	7.5125715	.002358491
425	18 06 25	76 765 625	20.6155281	7.5184730	.002352941
426	18 14 76	77 308 776	20.6397674	7.5243652	.002347418
427	18 23 29	77 854 483	20.6639783	7.5302482	.002341920
428	18 31 84	78 402 752	20.6881609	7.5361221	.002336449
429	18 40 41	78 953 589	20.7123152	7.5419867	.002331002
430	18 49 00	79 507 000	20.7364414	7.5478423	.002325581
431	18 57 61	80 062 991	20.7605395	7.5536888	.002320186
432	18 66 24	80 621 568	20.7846097	7.5595263	.002314815
433	18 74 89	81 182 737	20.8086520	7.5653548	.002309469
434	18 83 56	81 746 504	20.8326667	7.5711743	.002304147
435	18 92 25	82 312 875	20.8566536	7.5769849	.002298851
436	19 00 96	82 881 856	20.8806130	7.5827865	.002293578
437	19 09 69	83 453 453	20.9045450	7.5885793	.002288330
438	19 18 44	84 027 672	20.9284495	7.5943633	.002283105
439	19 27 21	84 604 519	20.9523268	7.6001385	.002277904
440	19 36 00	85 184 000	20.9761770	7.6059049	.002272727
441	19 44 81	85 766 121	21.0000000	7.6116626	.002267574
442	19 53 64	86 350 888	21.0237960	7.6174116	.002262443
443	19 62 49	86 938 307	21.0475652	7.6231519	.002257336
444	19 71 36	87 528 384	21.0713075	7.6288837	.002252252
445	19 80 25	88 121 125	21.0950231	7.6346067	.002247191
446	19 89 16	88 716 536	21.1187121	7.6403213	.002242152
447	19 98 09	89 314 623	21.1423745	7.6460272	.002237136
448	20 07 04	89 915 392	21.1660105	7.6517247	.002232143
449	20 16 01	90 518 849	21.1896201	7.6574138	.002227171
450	20 25 00	91 125 000	21.2132034	7.6630943	.002222222

TABLE 96 (*Continued*)

SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS, RECIPROCALS

Num.	Square	Cube	Square root	Cube root	Reciprocal
451	20 34 01	91 733 851	21.2367606	7.6687665	.002217295
452	20 43 04	92 345 408	21.2602916	7.6744303	.002212389
453	20 52 09	92 959 677	21.2837967	7.6800857	.002207506
454	20 61 16	93 576 664	21.3072758	7.6857328	.002202643
455	20 70 25	94 196 375	21.3307290	7.6913717	.002197802
456	20 79 36	94 818 816	21.3541565	7.6970023	.002192982
457	20 88 49	95 443 993	21.3775583	7.7026246	.002188184
458	20 97 64	96 071 912	21.4009346	7.7082388	.002183406
459	21 06 81	96 702 579	21.4242853	7.7138448	.002178649
460	21 16 00	97 336 000	21.4476106	7.7194426	.002173913
461	21 25 21	97 972 181	21.4709106	7.7250325	.002169197
462	21 34 44	98 611 128	21.4941853	7.7306141	.002164502
463	21 43 69	99 252 847	21.5174348	7.7361877	.002159827
464	21 52 96	99 897 344	21.5406592	7.7417532	.002155172
465	21 62 25	100 544 625	21.5638587	7.7473109	.002150538
466	21 71 56	101 194 696	21.5870331	7.7528606	.002145923
467	21 80 89	101 847 563	21.6101828	7.7584023	.002141328
468	21 90 24	102 503 232	21.6333077	7.7639361	.002136752
469	21 99 61	103 161 709	21.6564078	7.7694620	.002132196
470	22 09 00	103 823 000	21.6794834	7.7749801	.002127660
471	22 18 41	104 487 111	21.7025344	7.7804904	.002123142
472	22 27 84	105 154 048	21.7255610	7.7859928	.002118644
473	22 37 29	105 823 817	21.7485632	7.7914875	.002114165
474	22 46 76	106 496 424	21.7715411	7.7969745	.002109705
475	22 56 25	107 171 875	21.7944947	7.8024538	.002105263
476	22 65 76	107 850 176	21.8174242	7.8079254	.002100840
477	22 75 29	108 531 333	21.8403297	7.8133892	.002096436
478	22 84 84	109 215 352	21.8632111	7.8188456	.002092050
479	22 94 41	109 902 239	21.8860686	7.8242942	.002087683
480	23 04 00	110 592 000	21.9089023	7.8297353	.002083333
481	23 13 61	111 284 641	21.9317122	7.8351688	.002079002
482	23 23 24	111 980 168	21.9544984	7.8405949	.002074689
483	23 32 89	112 678 587	21.9772610	7.8460134	.002070393
484	23 42 56	113 379 904	22.0000000	7.8514244	.002066116
485	23 52 25	114 084 125	22.0227155	7.8568281	.002061856
486	23 61 96	114 791 256	22.0454077	7.8622242	.002057613
487	23 71 69	115 501 303	22.0680765	7.8676130	.002053388
488	23 81 44	116 214 272	22.0907220	7.8729944	.002049180
489	23 91 21	116 930 169	22.1133444	7.8783684	.002044990
490	24 01 00	117 649 000	22.1359436	7.8837352	.002040816
491	24 10 81	118 370 771	22.1585198	7.8890946	.002036660
492	24 20 64	119 095 488	22.1810730	7.8944468	.002032520
493	24 30 49	119 823 157	22.2036033	7.8997917	.002028398
494	24 40 36	120 553 784	22.2261108	7.9051294	.002024291
495	24 50 25	121 287 375	22.2485955	7.9104599	.002020202
496	24 60 16	122 023 936	22.2710575	7.9157832	.002016129
497	24 70 09	122 763 473	22.2934968	7.9210994	.002012072
498	24 80 04	123 505 992	22.3159136	7.9264085	.002008032
499	24 90 01	124 251 499	22.3383079	7.9317104	.002004008
500	25 00 00	125 000 000	22.3606798	7.9370053	.002000000

TABLE 96 (*Continued*)

SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS, RECIPROCALS

Num.	Square	Cube	Square root	Cube root	Reciprocal
501	25 10 01	125 751 501	22.3830293	7.9422931	.001996008
502	25 20 04	126 506 008	22.4053565	7.9475739	.001992032
503	25 30 09	127 263 527	22.4276615	7.9528477	.001988072
504	25 40 16	128 024 064	22.4499443	7.9581144	001984127
505	25 50 25	128 787 625	22.4722051	7.9633743	.001980198
506	25 60 36	129 554 216	22.4944438	7.9686271	.001976285
507	25 70 49	130 323 843	22.5166605	7.9738731	.001972387
508	25 80 64	131 096 512	22.5388553	7.9791122	.001968504
509	25 90 81	131 872 229	22.5610283	7.9843444	.001964637
510	26 01 00	132 651 000	22.5831796	7.9895697	.001960784
511	26 11 21	133 432 831	22.6053091	7.9947883	.001956947
512	26 21 44	134 217 728	22.6274170	8.0000000	.001953125
513	26 31 69	135 005 697	22.6495033	8.0052049	.001949318
514	26 41 96	135 796 744	22.6715681	8.0104032	.001945525
515	26 52 25	136 590 875	22.6936114	8.0155946	.001941748
516	26 62 56	137 388 096	22.7156334	8.0207794	.001937984
517	26 72 89	138 188 413	22.7376340	8.0259574	.001934236
518	26 83 24	138 991 832	22.7596134	8.0311287	.001930502
519	26 93 61	139 798 359	22.7815715	8.0362935	.001926782
520	27 04 00	140 608 000	22.8035085	8.0414515	.001923077
521	27 14 41	141 420 761	22.8254244	8.0466030	.001919386
522	27 24 84	142 236 648	22.8473193	8.0517479	.001915709
523	27 35 29	143 055 667	22.8691933	8.0568862	.001912046
524	27 45 76	143 877 824	22.8910463	8.0620180	.001908397
525	27 56 25	144 703 125	22.9128785	8.0671432	.001904762
526	27 66 76	145 531 576	22.9346899	8.0722620	.001901141
527	27 77 29	146 363 183	22.9564806	8.0773743	.001897533
528	27 87 84	147 197 952	22.9782506	8.0824800	.001893939
529	27 98 41	148 035 889	23.0000000	8.0875794	.001890359
530	28 09 00	148 877 000	23.0217289	8.0926723	.001886792
531	28 19 61	149 721 291	23.0434372	8.0977589	.001883239
532	28 30 24	150 568 768	23.0651252	8.1028390	.001879699
533	28 40 89	151 419 437	23.0867928	8.1079128	.001876173
534	28 51 56	152 273 304	23.1084400	8.1129803	.001872659
535	28 62 25	153 130 375	23.1300670	8.1180414	.001869159
536	28 72 96	153 990 656	23.1516738	8.1230962	.001865672
537	28 83 69	154 854 153	23.1732605	8.1281447	.001862197
538	28 94 44	155 720 872	23.1948270	8.1331870	.001858736
539	29 05 21	156 590 819	23.2163735	8.1382230	.001855288
540	29 16 00	157 464 000	23.2379001	8.1432529	.001851852
541	29 26 81	158 340 421	23.2594067	8.1482765	.001848429
542	29 37 64	159 220 088	23.2808935	8.1532939	.001845018
543	29 48 49	160 103 007	23.3023604	8.1583051	.001841621
544	29 59 36	160 989 184	23.3238076	8.1633102	.001838235
545	29 70 25	161 878 625	23.3452351	8.1683092	.001834862
546	29 81 16	162 771 336	23.3666429	8.1733020	.001831502
547	29 92 09	163 667 323	23.3880311	8.1782888	.001828154
548	30 03 04	164 566 592	23.4093998	8.1832695	.001824818
549	30 14 01	165 469 149	23.4307490	8.1882441	.001821494
550	30 25 00	166 375 000	23.4520788	8.1932127	.001818182

TABLE 96 (*Continued*)

SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS, RECIPROCALS

Num.	Square	Cube	Square root	Cube root	Reciprocal
551	30 36 01	167 284 151	23.4733892	8.1981753	.001814882
552	30 47 04	168 196 608	23.4946802	8.2031319	.001811594
553	30 58 09	169 112 377	23.5159520	8.2080825	.001808318
554	30 69 16	170 031 464	23.5372046	8.2130271	.001805054
555	30 80 25	170 953 875	23.5584380	8.2179657	.001801802
556	30 91 36	171 879 616	23.5796522	8.2228985	.001798561
557	31 02 49	172 808 693	23.6008474	8.2278254	.001795332
558	31 13 64	173 741 112	23.6220236	8.2327463	.001792115
559	31 24 81	174 676 879	23.6431808	8.2376614	.001788909
560	31 36 00	175 616 000	23.6643191	8.2425706	.001785714
561	31 47 21	176 558 481	23.6854386	8.2474740	.001782531
562	31 58 44	177 504 328	23.7065392	8.2523715	.001779359
563	31 69 69	178 453 547	23.7276210	8.2572633	.001776199
564	31 80 96	179 406 144	23.7486842	8.2621492	.001773050
565	31 92 25	180 362 125	23.7697286	8.2670294	.001769912
566	32 03 56	181 321 496	23.7907545	8.2719039	.001766784
567	32 14 89	182 284 263	23.8117618	8.2767726	.001763668
568	32 26 24	183 250 432	23.8327506	8.2816355	.001760563
569	32 37 61	184 220 009	23.8537209	8.2864928	.001757469
570	32 49 00	185 193 000	23.8746728	8.2913444	.001754386
571	32 60 41	186 169 411	23.8956063	8.2961903	.001751313
572	32 71 84	187 149 248	23.9165215	8.3010304	.001748252
573	32 83 29	188 132 517	23.9374184	8.3058651	.001745201
574	32 94 76	189 119 224	23.9582971	8.3106941	.001742160
575	33 06 25	190 109 375	23.9791576	8.3155175	.001739130
576	33 17 76	191 102 976	24.0000000	8.3203353	.001736111
577	33 29 29	192 100 033	24.0208243	8.3251475	.001733102
578	33 40 84	193 100 552	24.0416306	8.3299542	.001730104
579	33 52 41	194 104 539	24.0624188	8.3347553	.001727116
580	33 64 00	195 112 000	24.0831891	8.3395509	.001724138
581	33 75 61	196 122 941	24.1039416	8.3443410	.001721170
582	33 87 24	197 137 368	24.1246762	8.3491256	.001718213
583	33 98 89	198 155 287	24.1453929	8.3539047	.001715266
584	34 10 56	199 176 704	24.1660919	8.3586784	.001712329
585	34 22 25	200 201 625	24.1867732	8.3634466	.001709402
586	34 33 96	201 230 056	24.2074369	8.3682095	.001706485
587	34 45 69	202 262 003	24.2280829	8.3729668	.001703578
588	34 57 44	203 297 472	24.2487113	8.3777188	.001700680
589	34 69 21	204 336 469	24.2693222	8.3824653	.001697793
590	34 81 00	205 379 000	24.2899156	8.3872065	.001694915
591	34 92 81	206 425 071	24.3104916	8.3919423	.001692047
592	35 04 64	207 474 688	24.3310501	8.3966729	.001689189
593	35 16 49	208 527 857	24.3515913	8.4013981	.001686341
594	35 28 36	209 584 584	24.3721152	8.4061180	.001683502
595	35 40 25	210 644 875	24.3926218	8.4108326	.001680672
596	35 52 16	211 708 736	34.4131112	8.4155419	.001677852
597	35 64 09	212 776 173	24.4335834	8.4202460	.001675042
598	35 76 04	213 847 192	24.4540385	8.4249448	.001672241
599	35 88 01	214 921 799	24.4744765	8.4296383	.001669449
600	36 00 00	216 000 000	24.4948974	8.4343267	.001666667

TABLE 96 (*Continued*)

SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS, RECIPROCALS

Num.	Square	Cube	Square root	Cube root	Reciprocal
601	36 12 01	217 081 801	24.5153013	8.4390098	.001663894
602	36 24 04	218 167 208	24.5356883	8.4436877	.001661130
603	36 36 09	219 256 227	24.5560583	8.4483605	.001658375
604	36 48 16	220 348 864	24.5764115	8.4530281	.001655629
605	36 60 25	221 445 125	24.5967478	8.4576906	.001652893
606	36 72 36	222 545 016	24.6170673	8.4623479	.001650165
607	36 84 49	223 648 543	24.6373700	8.4670000	.001647446
608	36 96 64	224 755 712	24.6576560	8.4716471	.001644737
609	37 08 81	225 866 529	24.6779254	8.4762892	.001642036
610	37 21 00	226 981 000	24.6981781	8.4809261	.001639344
611	37 33 21	228 099 131	24.7184142	8.4855579	.001636661
612	37 45 44	229 220 928	24.7386338	8.4901848	.001633987
613	37 57 69	230 346 397	24.7588368	8.4948065	.001631321
614	37 69 96	231 475 544	24.7790234	8.4994233	.001628664
615	37 82 25	232 608 375	24.7991935	8.5040350	.001626016
616	37 94 56	233 744 896	24.8193473	8.5086417	.001623377
617	38 06 89	234 885 113	24.8394847	8.5132435	.001620746
618	38 19 24	236 029 032	24.8596058	8.5178403	.001618123
619	38 31 61	237 176 659	24.8797106	8.5224321	.001615509
620	38 44 00	238 328 000	24.8997992	8.5270189	.001612903
621	38 56 41	239 483 061	24.9198716	8.5316009	.001610306
622	38 68 84	240 641 848	24.9399278	8.5361780	.001607717
623	38 81 29	241 804 367	24.9599679	8.5407501	.001605136
624	38 93 76	242 970 624	24.9799920	8.5453173	.001602564
625	39 06 25	244 140 625	25.0000000	8.5498797	.001600000
626	39 18 76	245 314 376	25.0199920	8.5544372	.001597444
627	39 31 29	246 491 883	25.0399681	8.5589899	.001594896
628	39 43 84	247 673 152	25.0599282	8.5635377	.001592357
629	39 56 41	248 858 189	25.0798724	8.5680807	.001589825
630	39 69 00	250 047 000	25.0998008	8.5726189	.001587302
631	39 81 61	251 239 591	25.1197134	8.5771523	.001584786
632	39 94 24	252 435 968	25.1396102	8.5816809	.001582278
633	40 06 89	253 636 137	25.1594913	8.5862047	.001579779
634	40 19 56	254 840 104	25.1793566	8.5907238	.001577287
635	40 32 25	256 047 875	25.1992063	8.5952380	.001574803
636	40 44 96	257 259 456	25.2190404	8.5997476	.001572327
637	40 57 69	258 474 853	25.2388589	8.6042525	.001569859
638	40 70 44	259 694 072	25.2586619	8.6087526	.001567398
639	40 83 21	260 917 119	25.2784493	8.6132480	.001564945
640	40 96 00	262 144 000	25.2982213	8.6177388	.001562500
641	41 08 81	263 374 721	25.3179778	8.6222248	.001560062
642	41 21 64	264 609 288	25.3377189	8.6267063	.001557632
643	41 34 49	265 847 707	25.3574447	8.6311830	.001555210
644	41 47 36	267 089 984	25.3771551	8.6356551	.001552795
645	41 60 25	268 336 125	25.3968502	8.6401226	.001550388
646	41 73 16	269 586 136	25.4165301	8.6445855	.001547988
647	41 86 09	270 840 023	25.4361947	8.6490437	.001545595
648	41 99 04	272 097 792	25.4558441	8.6534974	.001543210
649	42 12 01	273 359 449	25.4754784	8.6579465	.001540832
650	42 25 00	274 625 000	25.4950976	8.6623911	.001538462

TABLE 96 (*Continued*)

SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS, RECIPROCALS

Num.	Square	Cube	Square root	Cube root	Reciprocal
651	42 38 01	275 894 451	25.5147016	8.6668310	.001536098
652	42 51 04	277 167 808	25.5342907	8.6712665	.001533742
653	42 64 09	278 445 077	25.5538647	8.6756974	.001531394
654	42 77 16	279 726 264	25.5734237	8.6801237	.001529052
655	42 90 25	281 011 375	25.5929678	8.6845456	.001526718
656	43 03 36	282 300 416	25.6124969	8.6889630	.001524390
657	43 16 49	283 593 393	25.6320112	8.6933759	.001522070
658	43 29 64	284 890 312	25.6515107	8.6977843	.001519757
659	43 42 81	286 191 179	25.6709953	8.7021882	.001517451
660	43 56 00	287 496 000	25.6904652	8.7065877	.001515152
661	43 69 21	288 804 781	25.7099203	8.7109827	.001512859
662	43 82 44	290 117 528	25.7293607	8.7153734	.001510574
663	43 95 69	291 434 247	25.7487864	8.7197596	.001508296
664	44 08 96	292 754 944	25.7681975	8.7241414	.001506024
665	44 22 25	294 079 625	25.7875939	8.7285187	.001503759
666	44 35 56	295 408 296	25.8069758	8.7328918	.001501502
667	44 48 89	296 740 963	25.8263431	8.7372604	.001499250
668	44 62 24	298 077 632	25.8456960	8.7416246	.001497006
669	44 75 61	299 418 309	25.8650343	8.7459846	.001494768
670	44 89 00	300 763 000	25.8843582	8.7503401	.001492537
671	45 02 41	302 111 711	25.9036677	8.7546913	.001490313
672	45 15 84	303 464 448	25.9229628	8.7590383	.001488095
673	45 29 29	304 821 217	25.9422435	8.7633809	.001485884
674	45 42 76	306 182 024	25.9615100	8.7677192	.001483680
675	45 56 25	307 546 875	25.9807621	8.7720532	.001481481
676	45 69 76	308 915 776	26.0000000	8.7763830	.001479290
677	45 83 29	310 288 733	26.0192237	8.7807084	.001477105
678	45 96 84	311 665 752	26.0384331	8.7850296	.001474926
679	46 10 41	313 046 839	26.0576284	8.7893466	.001472754
680	46 24 00	314 432 000	26.0768096	8.7936593	.001470588
681	46 37 61	315 821 241	26.0959767	8.7979679	.001468429
682	46 51 24	317 214 568	26.1151297	8.8022721	.001466276
683	46 64 89	318 611 987	26.1342687	8.8065722	.001464129
684	46 78 56	320 013 504	26.1533937	8.8108681	.001461988
685	46 92 25	321 419 125	26.1725047	8.8151598	.001459854
686	47 05 96	322 828 856	26.1916017	8.8194474	.001457726
687	47 19 69	324 242 703	26.2106848	8.8237307	.001455604
688	47 33 44	325 660 672	26.2297541	8.8280099	.001453488
689	47 47 21	327 082 769	26.2488095	8.8322850	.001451379
690	47 61 00	328 509 000	26.2678511	8.8365559	.001449275
691	47 74 81	329 939 371	26.2868789	8.8408227	.001447178
692	47 88 64	331 373 888	26.3058929	8.8450854	.001445087
693	48 02 49	332 812 557	26.3248932	8.8493440	.001443001
694	48 16 36	334 255 384	26.3438797	8.8535985	.001440922
695	48 30 25	335 702 375	26.3628527	8.8578489	.001438849
696	48 44 16	337 153 536	26.3818119	8.8620952	.001436782
697	48 58 09	338 608 873	26.4007576	8.8663375	.001434720
698	48 72 04	340 068 392	26.4196896	8.8705757	.001432665
699	48 86 01	341 532 099	26.4386081	8.8748099	.001430615
700	49 00 00	343 000 000	26.4575131	8.8790400	.001428571

TABLE 96 (*Continued*)

SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS, RECIPROCALS

Num.	Square	Cube	Square root	Cube root	Reciprocal
701	49 14 01	344 472 101	26.4764046	8.8832661	.001426534
702	49 28 04	345 948 408	26.4952826	8.8874882	.001424501
703	49 42 09	347 428 927	26.5141472	8.8917063	.001422475
704	49 56 16	348 913 664	26.5329983	8.8959204	.001420455
705	49 70 25	350 402 625	26.5518361	8.9001304	.001418440
706	49 84 36	351 895 816	26.5706605	8.9043366	.001416431
707	49 98 49	353 393 243	26.5894716	8.9085387	.001414427
708	50 12 64	354 894 912	26.6082694	8.9127369	.001412429
709	50 26 81	356 400 829	26.6270539	8.9169311	.001410437
710	50 41 00	357 911 000	26.6458252	8.9211214	.001408451
711	50 55 21	359 425 431	26.6645833	8.9253078	.001406470
712	50 69 44	360 944 128	26.6833281	8.9294902	.001404494
713	50 83 69	362 467 097	26.7020598	8.9336687	.001402525
714	50 97 96	363 994 344	26.7207784	8.9378433	.001400560
715	51 12 25	365 525 875	26.7394839	8.9420140	.001398601
716	51 26 56	367 061 696	26.7581763	8.9461809	.001396648
717	51 40 89	368 601 813	26.7768557	8.9503438	.001394700
718	51 55 24	370 146 232	26.7955220	8.9545029	.001392758
719	51 69 61	371 694 959	26.8141754	8.9586581	.001390821
720	51 84 00	373 248 000	26.8328157	8.9628095	.001388889
721	51 98 41	374 805 361	26.8514432	8.9669570	.001386963
722	52 12 84	376 367 048	26.8700577	8.9711007	.001385042
723	52 27 29	377 933 067	26.8886593	8.9752406	.001383126
724	52 41 76	379 503 424	26.9072481	8.9793766	.001381215
725	52 56 25	381 078 125	26.9258240	8.9835089	.001379310
726	52 70 76	382 657 176	26.9443872	8.9876373	.001377410
727	52 85 29	384 240 583	26.9629375	8.9917620	.001375516
728	52 99 84	385 828 352	26.9814751	8.9958829	.001373626
729	53 14 41	387 420 489	27.0000000	9.0000000	.001371742
730	53 29 00	389 017 000	27.0185122	9.0041134	.001369863
731	53 43 61	390 617 891	27.0370117	9.0082229	.001367989
732	53 58 24	392 223 168	27.0554985	9.0123288	.001366120
733	53 72 89	393 832 837	27.0739727	9.0164309	.001364256
734	53 87 56	395 446 904	27.0924344	9.0205293	.001362398
735	54 02 25	397 065 375	27.1108834	9.0246239	.001360544
736	54 16 96	398 688 256	27.1293199	9.0287149	.001358696
737	54 31 69	400 315 553	27.1477439	9.0328021	.001356852
738	54 46 44	401 947 272	27.1661554	9.0368857	.001355014
739	54 61 21	403 583 419	27.1845544	9.0409655	.001353180
740	54 76 00	405 224 000	27.2029410	9.0450417	.001351351
741	54 90 81	406 869 021	27.2213152	9.0491142	.001349528
742	55 05 64	408 518 488	27.2396769	9.0531831	.001347709
743	55 20 49	410 172 407	27.2580263	9.0572482	.001345895
744	55 35 36	411 830 784	27.2763634	9.0613098	.001344086
745	55 50 25	413 493 625	27.2946881	9.0653677	.001342282
746	55 65 16	415 160 936	27.3130006	9.0694220	.001340483
747	55 80 09	416 832 723	27.3313007	9.0734726	.001338688
748	55 95 04	418 508 992	27.3495887	9.0775197	.001336898
749	56 10 01	420 189 749	27.3678644	9.0815631	.001335113
750	56 25 00	421 875 000	27.3861279	9.0856030	.001333333

TABLE 96 (*Continued*)

SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS, RECIPROCALS

Num.	Square	Cube	Square root	Cube root	Reciprocal
751	56 40 01	423 564 751	27.4043792	9.0896392	.001331558
752	56 55 04	425 259 008	27.4226184	9.0936719	.001329787
753	56 70 09	426 957 777	27.4408455	9.0977010	.001328021
754	56 85 16	428 661 064	27.4590604	9.1017265	.001326260
755	57 00 25	430 368 875	27.4772633	9.1057485	.001324503
756	57 15 36	432 081 216	27.4954542	9.1097669	.001322751
757	57 30 49	433 798 093	27.5136330	9.1137818	.001321004
758	57 45 64	435 519 512	27.5317998	9.1177931	.001319261
759	57 60 81	437 245 479	27.5499546	9.1218010	.001317523
760	57 76 00	438 976 000	27.5680975	9.1258053	.001315789
761	57 91 21	440 711 081	27.5862284	9.1298061	.001314060
762	58 06 44	442 450 728	27.6043475	9.1338034	.001312336
763	58 21 69	444 194 947	27.6224546	9.1377971	.001310616
764	58 36 96	445 943 744	27.6405499	9.1417874	.001308901
765	58 52 25	447 697 125	27.6586334	9.1457742	.001307190
766	58 67 56	449 455 096	27.6767050	9.1497576	.001305483
767	58 82 89	451 217 663	27.6947648	9.1537375	.001303781
768	58 98 24	452 984 832	27.7128129	9.1577139	.001302083
769	59 13 61	454 756 609	27.7308492	9.1616869	.001300390
770	59 29 00	456 533 000	27.7488739	9.1656565	.001298701
771	59 44 41	458 314 011	27.7668868	9.1696225	.001297017
772	59 59 84	460 099 648	27.7848880	9.1735852	.001295337
773	59 75 29	461 889 917	27.8028775	9.1775445	.001293661
774	59 90 76	463 684 824	27.8208555	9.1815003	.001291990
775	60 06 25	465 484 375	27.8388218	9.1854527	.001290323
776	60 21 76	467 288 576	27.8567766	9.1894018	.001288660
777	60 37 29	469 097 433	27.8747197	9.1933474	.001287001
778	60 52 84	470 910 952	27.8926514	9.1972897	.001285347
779	60 68 41	472 729 139	27.9105715	9.2012286	.001283697
780	60 84 00	474 552 000	27.9284801	9.2051641	.001282051
781	60 99 61	476 379 541	27.9463772	9.2090962	.001280410
782	61 15 24	478 211 768	27.9642629	9.2130250	.001278772
783	61 30 89	480 048 687	27.9821372	9.2169505	.001277139
784	61 46 56	481 890 304	28.0000000	9.2208726	.001275510
785	61 62 25	483 736 625	28.0178515	9.2247914	.001273885
786	61 77 96	485 587 656	28.0356915	9.2287068	.001272265
787	61 93 69	487 443 403	28.0535203	9.2326189	.001270648
788	62 09 44	489 303 872	28.0713377	9.2365277	.001269036
789	62 25 21	491 169 069	28.0891438	9.2404333	.001267427
790	62 41 00	493 039 000	28.1069386	9.2443355	.001265823
791	62 56 81	494 913 671	28.1247222	9.2482344	.001264223
792	62 72 64	496 793 088	28.1424946	9.2521300	.001262626
793	62 88 49	498 677 257	28.1602557	9.2560224	.001261034
794	63 04 36	500 566 184	28.1780056	9.2599114	.001259446
795	63 20 25	502 459 875	28.1957444	9.2637973	.001257862
796	63 36 16	504 358 336	28.2134720	9.2676798	.001256281
797	63 52 09	506 261 573	28.2311884	9.2715592	.001254705
798	63 68 04	508 169 592	28.2488938	9.2754352	.001253133
799	63 84 01	510 082 399	28.2665881	9.2793081	.001251564
800	64 00 00	512 000 000	28.2842712	9.2831777	.001250000

TABLE 96 (*Continued*)

SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS, RECIPROCALS

Num.	Square	Cube	Square root	Cube root	Reciprocal
801	64 16 01	513 922 401	28.3019434	9.2870440	.001248439
802	64 32 04	515 849 608	28.3196045	9.2909072	.001246883
803	64 48 09	517 781 627	28.3372546	9.2947671	.001245330
804	64 64 16	519 718 464	28.3548938	9.2986239	.001243781
805	64 80 25	521 660 125	28.3725219	9.3024775	.001242236
806	64 96 36	523 606 616	28.3901391	9.3063278	.001240695
807	65 12 49	525 557 943	28.4077454	9.3101750	.001239157
808	65 28 64	527 514 112	28.4253408	9.3140190	.001237624
809	65 44 81	529 475 129	28.4429253	9.3178599	.001236094
810	65 61 00	531 441 000	28.4604989	9.3216975	.001234568
811	65 77 21	533 411 731	28.4780617	9.3255320	.001233046
812	65 93 44	535 387 328	28.4956137	9.3293634	.001231527
813	66 09 69	537 367 797	28.5131549	9.3331916	.001230012
814	66 25 96	539 353 144	28.5306852	9.3370167	.001228501
815	66 42 25	541 343 375	28.5482048	9.3408386	.001226994
816	66 58 56	543 338 496	28.5657137	9.3446575	.001225490
817	66 74 89	545 338 513	28.5832119	9.3484731	.001223990
818	66 91 24	547 343 432	28.6006993	9.3522857	.001222494
819	67 07 61	549 353 259	28.6181760	9.3560952	.001221001
820	67 24 00	551 368 000	28.6356421	9.3599016	.001219512
821	67 40 41	553 387 661	28.6530976	9.3637049	.001218027
822	67 56 84	555 412 248	28.6705424	9.3675051	.001216545
823	67 73 29	557 441 767	28.6879766	9.3713022	.001215067
824	67 89 76	559 476 224	28.7054002	9.3750963	.001213592
825	68 06 25	561 515 625	28.7228132	9.3788873	.001212121
826	68 22 76	563 559 976	28.7402157	9.3826752	.001210654
827	68 39 29	565 609 283	28.7576077	9.3864600	.001209190
828	68 55 84	567 663 552	28.7749891	9.3902419	.001207729
829	68 72 41	569 722 789	28.7923601	9.3940206	.001206273
830	68 89 00	571 787 000	28.8097206	9.3977964	.001204819
831	69 05 61	573 856 191	28.8270706	9.4015691	.001203369
832	69 22 24	575 930 368	28.8444102	9.4053387	.001201923
833	69 38 89	578 009 537	28.8617394	9.4091054	.001200480
834	69 55 56	580 093 704	28.8790582	9.4128690	.001199041
835	69 72 25	582 182 875	28.8963666	9.4166297	.001197605
836	69 88 96	584 277 056	28.9136646	9.4203873	.001196172
837	70 05 69	586 376 253	28.9309523	9.4241420	.001194743
838	70 22 44	588 480 472	28.9482297	9.4278936	.001193317
839	70 39 21	590 589 719	28.9654967	9.4316423	.001191895
840	70 56 00	592 704 000	28.9827535	9.4353880	.001190476
841	70 72 81	594 823 321	29.0000000	9.4391307	.001189061
842	70 89 64	596 947 688	29.0172363	9.4428704	.001187648
843	71 06 49	599 077 107	29.0344623	9.4466072	.001186240
844	71 23 36	601 211 584	29.0516781	9.4503410	.001184834
845	71 40 25	603 351 125	29.0688837	9.4540719	.001183432
846	71 57 16	605 495 736	29.0860791	9.4577999	.001182033
847	71 74 09	607 645 423	29.1032644	9.4615249	.001180638
848	71 91 04	609 800 192	29.1204396	9.4652470	.001179245
849	72 08 01	611 960 049	29.1376046	9.4689661	.001177856
850	72 25 00	614 125 000	29.1547595	9.4726824	.001176471

TABLE 96 (*Continued*)

SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS, RECIPROCALS

Num.	Square	Cube	Square root	Cube root	Reciprocal
851	72 42 01	616 295 051	29.1719043	9.4763957	.001175088
852	72 59 04	618 470 208	29.1890390	9.4801061	.001173709
853	72 76 09	620 650 477	29.2061637	9.4838136	.001172333
854	72 93 16	622 835 864	29.2232784	9.4875182	.001170960
855	73 10 25	625 026 375	29.2403830	9.4912200	.001169591
856	73 27 36	627 222 016	29.2574777	9.4949188	.001168224
857	73 44 49	629 422 793	29.2745623	9.4986147	.001166861
858	73 61 64	631 628 712	29.2916370	9.5023078	.001165501
859	73 78 81	633 839 779	29.3087018	9.5059980	.001164144
860	73 96 00	636 056 000	29.3257566	9.5096854	.001162791
861	74 13 21	638 277 381	29.3428015	9.5133699	.001161440
862	74 30 44	640 503 928	29.3598365	9.5170515	.001160093
863	74 47 69	642 735 647	29.3768616	9.5207303	.001158749
864	74 64 96	644 972 544	29.3938769	9.5244063	.001157407
865	74 82 25	647 214 625	29.4108823	9.5280794	.001156069
866	74 99 56	649 461 896	29.4278779	9.5317497	.001154734
867	75 16 89	651 714 363	29.4448637	9.5354172	.001153403
868	75 34 24	653 972 032	29.4618397	9.5390818	.001152074
869	75 51 61	656 234 909	29.4788059	9.5427437	.001150748
870	75 69 00	658 503 000	29.4957624	9.5464027	.001149425
871	75 86 41	660 776 311	29.5127091	9.5500589	.001148106
872	76 03 84	663 054 848	29.5296461	9.5537123	.001146789
873	76 21 29	665 338 617	29.5465734	9.5573630	.001145475
874	76 38 76	667 627 624	29.5634910	9.5610108	.001144165
875	76 56 25	669 921 875	29.5803989	9.5646559	.001142857
876	76 73 76	672 221 376	29.5972972	9.5682982	.001141553
877	76 91 29	674 526 133	29.6141858	9.5719377	.001140251
878	77 08 84	676 836 152	29.6310648	9.5755745	.001138952
879	77 26 41	679 151 439	29.6479342	9.5792085	.001137656
880	77 44 00	681 472 000	29.6647939	9.5828397	.001136364
881	77 61 61	683 797 841	29.6816442	9.5864682	.001135074
882	77 79 24	686 128 968	29.6984848	9.5900939	.001133787
883	77 96 89	688 465 387	29.7153159	9.5937169	.001132503
884	78 14 56	690 807 104	29.7321375	9.5973373	.001131222
885	78 32 25	693 154 125	29.7489496	9.6009548	.001129944
886	78 49 96	695 506 456	29.7657521	9.6045696	.001128668
887	78 67 69	697 864 103	29.7825452	9.6081817	.001127396
888	78 85 44	700 227 072	29.7993289	9.6117911	.001126126
889	79 03 21	702 595 369	29.8161030	9.6153977	.001124859
890	79 21 00	704 969 000	29.8328678	9.6190017	.001123596
891	79 38 81	707 347 971	29.8496231	9.6226030	.001122334
892	79 56 64	709 732 288	29.8663690	9.6262016	.001121076
893	79 74 49	712 121 957	29.8831056	9.6297975	.001119821
894	79 92 36	714 516 984	29.8998328	9.6333907	.001118568
895	80 10 25	716 917 375	29.9165506	9.6369812	.001117318
896	80 28 16	719 323 136	29.9332591	9.6405690	.001116071
897	80 46 09	721 734 273	29.9499583	9.6441542	.001114827
898	80 64 04	724 150 792	29.9666481	9.6477367	.001113586
899	80 82 01	726 572 699	29.9833287	9.6513166	.001112347
900	81 00 00	729 000 000	30.0000000	9.6548938	.001111111

TABLE 96 (*Continued*)

SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS, RECIPROCALS

Num.	Square	Cube	Square root	Cube root	Reciprocal
901	81 18 01	731 432 701	30.0166620	9.6584684	.001109878
902	81 36 04	733 870 808	30.0333148	9.6620403	.001108647
903	81 54 09	736 314 327	30.0499584	9.6656096	.001107420
904	81 72 16	738 763 264	30.0665928	9.6691762	.001106195
905	81 90 25	741 217 625	30.0832179	9.6727403	.001104972
906	82 08 36	743 677 416	30.0998339	9.6763017	.001103753
907	82 26 49	746 142 643	30.1164407	9.6798604	.001102536
908	82 44 64	748 613 312	30.1330383	9.6834166	.001101322
909	82 62 81	751 089 429	30.1496269	9.6869701	.001100110
910	82 81 00	753 571 000	30.1662063	9.6905211	.001098901
911	82 99 21	756 058 031	30.1827765	9.6940694	.001097695
912	83 17 44	758 550 528	30.1993377	9.6976151	.001096491
913	83 35 69	761 048 497	30.2158899	9.7011583	.001095290
914	83 53 96	763 551 944	30.2324329	9.7046989	.001094092
915	83 72 25	766 060 875	30.2489669	9.7082369	.001092896
916	83 90 56	768 575 296	30.2654919	9.7117723	.001091703
917	84 08 89	771 095 213	30.2820079	9.7153051	.001090513
918	84 27 24	773 620 632	30.2985148	9.7188354	.001089325
919	84 45 61	776 151 559	30.3150128	9.7223631	.001088139
920	84 64 00	778 688 000	30.3315018	9.7258883	.001086957
921	84 82 41	781 229 961	30.3479818	9.7294109	.001085776
922	85 00 84	783 777 448	30.3644529	9.7329309	.001084599
923	85 19 29	786 330 467	30.3809151	9.7364484	.001083424
924	85 37 76	788 889 024	30.3973683	9.7399634	.001082251
925	85 56 25	791 453 125	30.4138127	9.7434758	.001081081
926	85 74 76	794 022 776	30.4302481	9.7469857	.001079914
927	85 93 29	796 597 983	30.4466747	9.7504930	.001078749
928	86 11 84	799 178 752	30.4630924	9.7539979	.001077586
929	86 30 41	801 765 089	30.4795013	9.7575002	.001076426
930	86 49 00	804 357 000	30.4959014	9.7610001	.001075269
931	86 67 61	806 954 491	30.5122926	9.7644974	.001074114
932	86 86 24	809 557 568	30.5286750	9.7679922	.001072961
933	87 04 89	812 166 237	30.5450487	9.7714845	.001071811
934	87 23 56	814 780 504	30.5614136	9.7749743	.001070664
935	87 42 25	817 400 375	30.5777697	9.7784616	.001069519
936	87 60 96	820 025 856	30.5941171	9.7819466	.001068376
937	87 79 69	822 656 953	30.6104557	9.7854288	.001067236
938	87 98 44	825 293 672	30.6267857	9.7889087	.001066098
939	88 17 21	827 936 019	30.6431069	9.7923861	.001064963
940	88 36 00	830 584 000	30.6594194	9.7958611	.001063830
941	88 54 81	833 237 621	30.6757233	9.7993336	.001062699
942	88 73 64	835 896 888	30.6920185	9.8028036	.001061571
943	88 92 49	838 561 807	30.7083051	9.8062711	.001060445
944	89 11 36	841 232 384	30.7245830	9.8097362	.001059322
945	89 30 25	843 908 625	30.7408523	9.8131989	.001058201
946	89 49 16	846 590 536	30.7571130	9.8166591	.001057082
947	89 68 09	849 278 123	30.7733651	9.8201169	.001055966
948	89 87 04	851 971 392	30.7896086	9.8235723	.001054852
949	90 06 01	854 670 349	30.8058436	9.8270252	.001053741
950	90 25 00	857 375 000	30.8220700	9.8304757	.001052632

TABLE 96 (*Concluded*)

SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS, RECIPROCALS

Num.	Square	Cube	Square root	Cube root	Reciprocal
951	90 44 01	860 085 351	30.8382879	9.8339238	.001051525
952	90 63 04	862 801 408	30.8544972	9.8373695	.001050420
953	90 82 09	865 523 177	30.8706981	9.8408127	.001049318
954	91 01 16	868 250 664	30.8868904	9.8442536	.001048218
955	91 20 25	870 983 875	30.9030743	9.8476920	.001047120
956	91 39 36	873 722 816	30.9192497	9.8511280	.001046025
957	91 58 49	876 467 493	30.9354166	9.8545617	.001044932
958	91 77 64	879 217 912	30.9515751	9.8579929	.001043841
959	91 96 81	881 974 079	30.9677251	9.8614218	.001042753
960	92 16 00	884 736 000	30.9838668	9.8648483	.001041667
961	92 35 21	887 503 681	31.0000000	9.8682724	.001040583
962	92 54 44	890 277 128	31.0161248	9.8716941	.001039501
963	92 73 69	893 056 347	31.0322413	9.8751135	.001038422
964	92 92 96	895 841 344	31.0483494	9.8785305	.001037344
965	93 12 25	898 632 125	31.0644491	9.8819451	.001036269
966	93 31 56	901 428 696	31.0805405	9.8853574	.001035197
967	93 50 89	904 231 063	31.0966236	9.8887673	.001034126
968	93 70 24	907 039 232	31.1126984	9.8921749	.001033058
969	93 89 61	909 853 209	31.1287648	9.8955801	.001031992
970	94 09 00	912 673 000	31.1448230	9.8989830	.001030928
971	94 28 41	915 498 611	31.1608729	9.9023835	.001029866
972	94 47 84	918 330 048	31.1769145	9.9057817	.001028807
973	94 67 29	921 167 317	31.1929479	9.9091776	.001027749
974	94 86 76	924 010 424	31.2089731	9.9125712	.001026694
975	95 06 25	926 859 375	31.2249900	9.9159624	.001025641
976	95 25 76	929 714 176	31.2409987	9.9193513	.001024590
977	95 45 29	932 574 833	31.2569992	9.9227379	.001023541
973	95 64 84	935 441 352	31.2729915	9.9261222	.001022495
979	95 84 41	938 313 739	31.2889757	9.9295042	.001021450
980	96 04 00	941 192 000	31.3049517	9.9328839	.001020408
981	96 23 61	944 076 141	31.3209195	9.9362613	.001019368
982	96 43 24	946 966 168	31.3368792	9.9396363	.001018330
983	96 62 89	949 862 087	31.3528308	9.9430092	.001017294
984	96 82 56	952 763 904	31.3687743	9.9463797	.001016260
985	97 02 25	955 671 625	31.3847097	9.9497479	.001015228
986	97 21 96	958 585 256	31.4006369	9.9531138	.001014199
987	97 41 69	961 504 803	31.4165561	9.9564775	.001013171
988	97 61 44	964 430 272	31.4324673	9.9598389	.001012146
989	97 81 21	967 361 669	31.4483704	9.9631981	.001011122
990	98 01 00	970 299 000	21.4642654	9.9665549	.001010101
991	98 20 81	973 242 271	31.4801525	9.9699095	.001009082
992	98 40 64	976 191 488	31.4960315	9.9732619	.001008065
993	98 60 49	979 146 657	31.5119025	9.9766120	.001007049
994	98 80 36	982 107 784	31.5277655	9.9799599	.001006036
995	99 00 25	985 074 875	31.5436206	9.9833055	.001005025
996	99 20 16	988 047 936	31.5594677	9.9866488	.001004016
997	99 40 09	991 026 973	31.5753068	9.9899900	.001003009
998	99 60 04	994 011 992	31.5911380	9.9933289	.001002004
999	99 80 01	997 002 999	31.6069613	9.9966656	.001001001
1,000	1,00 00 00	1,000 000 000	31.6227766	10.0000000	.001000000

TABLE 97.—SQUARE ROOTS OF NUMBERS FROM 1000 TO 10000

Number	00	10	20	30	40	50	60	70	80	90
1,000	31.62	31.78	31.94	32.09	32.25	32.40	32.56	32.71	32.86	33.02
1,100	33.17	33.32	33.47	33.62	33.76	33.91	34.06	34.21	34.35	34.50
1,200	34.64	34.79	34.93	35.07	35.21	35.36	35.50	35.64	35.78	35.92
1,300	36.06	36.19	36.33	36.47	36.61	36.74	36.88	37.01	37.15	37.28
1,400	37.42	37.55	37.68	37.82	37.95	38.08	38.21	38.34	38.47	38.60
1,500	38.73	38.86	38.99	39.12	39.24	39.37	39.50	39.62	39.75	39.87
1,600	40.00	40.12	40.25	40.37	40.50	40.62	40.74	40.87	40.99	41.11
1,700	41.23	41.35	41.47	41.59	41.71	41.83	41.95	42.07	42.19	42.31
1,800	42.43	42.54	42.66	42.78	42.90	43.01	43.13	43.24	43.36	43.47
1,900	43.59	43.70	43.82	43.93	44.05	44.16	44.27	44.38	44.50	44.61
2,000	44.72	44.83	44.94	45.06	45.17	45.28	45.39	45.50	45.61	45.72
2,100	45.83	45.93	46.04	46.15	46.26	46.37	46.48	46.58	46.69	46.80
2,200	46.90	47.01	47.12	47.22	47.33	47.43	47.54	47.64	47.75	47.85
2,300	47.96	48.06	48.17	48.27	48.37	48.48	48.58	48.68	48.79	48.89
2,400	48.99	49.09	49.19	49.30	49.40	49.50	49.60	49.70	49.80	49.90
2,500	50.00	50.10	50.20	50.30	50.40	50.50	50.60	50.70	50.79	50.89
2,600	50.99	51.09	51.19	51.28	51.38	51.48	51.58	51.67	51.77	51.87
2,700	51.96	52.06	52.15	52.25	52.35	52.44	52.54	52.63	52.73	52.82
2,800	52.92	53.01	53.10	53.20	53.29	53.39	53.48	53.57	53.67	53.76
2,900	53.85	53.94	54.04	54.13	54.22	54.31	54.41	54.50	54.59	54.68
3,000	54.77	54.86	54.95	55.05	55.14	55.23	55.32	55.41	55.50	55.59
3,100	55.68	55.77	55.86	55.95	56.04	56.12	56.21	56.30	56.39	56.48
3,200	56.57	56.66	56.75	56.83	56.92	57.01	57.10	57.18	57.27	57.36
3,300	57.45	57.53	57.62	57.71	57.79	57.88	57.97	58.05	58.14	58.22
3,400	58.31	58.40	58.48	58.57	58.65	58.74	58.82	58.91	58.99	59.08
3,500	59.16	59.25	59.33	59.41	59.50	59.58	59.67	59.75	59.83	59.92
3,600	60.00	60.08	60.17	60.25	60.33	60.42	60.50	60.58	60.66	60.75
3,700	60.83	60.91	60.99	61.07	61.16	61.24	61.32	61.40	61.48	61.56
3,800	61.64	61.73	61.81	61.89	61.97	62.05	62.13	62.21	62.29	62.37
3,900	62.45	62.53	62.61	62.69	62.77	62.85	62.93	63.01	63.09	63.17
4,000	63.25	63.32	63.40	63.48	63.56	63.64	63.72	63.80	63.87	63.95
4,100	64.03	64.11	64.19	64.27	64.34	64.42	64.50	64.58	64.65	64.73
4,200	64.81	64.88	64.96	65.04	65.12	65.19	65.27	65.35	65.42	65.50
4,300	65.57	65.65	65.73	65.80	65.88	65.95	66.03	66.11	66.18	66.26
4,400	66.33	66.41	66.48	66.56	66.63	66.71	66.78	66.86	66.93	67.01
4,500	67.08	67.16	67.23	67.31	67.38	67.45	67.53	67.60	67.68	67.75
4,600	67.82	67.90	67.97	68.04	68.12	68.19	68.26	68.34	68.41	68.48
4,700	68.56	68.63	68.70	68.77	68.85	68.92	68.99	69.07	69.14	69.21
4,800	69.28	69.35	69.43	69.50	69.57	69.64	69.71	69.79	69.86	69.93
4,900	70.00	70.07	70.14	70.21	70.29	70.36	70.43	70.50	70.57	70.64
5,000	70.71	70.78	70.85	70.92	70.99	71.06	71.13	71.20	71.27	71.34
5,100	71.41	71.48	71.55	71.62	71.69	71.76	71.83	71.90	71.97	72.04
5,200	72.11	72.18	72.25	72.32	72.39	72.46	72.53	72.59	72.66	72.73
5,300	72.80	72.87	72.94	73.01	73.08	73.14	73.21	73.28	73.35	73.42
5,400	73.48	73.55	73.62	73.69	73.76	73.82	73.89	73.96	74.03	74.09

TABLE 97 (*Concluded*)

SQUARE ROOTS OF NUMBERS FROM 1000 TO 10000

Number	00	10	20	30	40	50	60	70	80	90
5,500	74.16	74.23	74.30	74.36	74.43	74.50	74.57	74.63	74.70	74.77
5,600	74.83	74.90	74.97	75.03	75.10	75.17	75.23	75.30	75.37	75.43
5,700	75.50	75.56	75.63	75.70	75.76	75.83	75.89	75.96	76.03	76.09
5,800	76.16	76.22	76.29	76.35	76.42	76.49	76.55	76.62	76.68	76.75
5,900	76.81	76.88	76.94	77.01	77.07	77.14	77.20	77.27	77.33	77.40
6,000	77.46	77.52	77.59	77.65	77.72	77.78	77.85	77.91	77.97	78.04
6,100	78.10	78.17	78.23	78.29	78.36	78.42	78.49	78.55	78.61	78.68
6,200	78.74	78.80	78.87	78.93	78.99	79.06	79.12	79.18	79.25	79.31
6,300	79.37	79.44	79.50	79.56	79.62	79.69	79.75	79.81	79.87	79.94
6,400	80.00	80.06	80.12	80.19	80.25	80.31	80.37	80.44	80.50	80.56
6,500	80.62	80.68	80.75	80.81	80.87	80.93	80.99	81.06	81.12	81.18
6,600	81.24	81.30	81.36	81.42	81.49	81.55	81.61	81.67	81.73	81.79
6,700	81.85	81.91	81.98	82.04	82.10	82.16	82.22	82.28	82.34	82.40
6,800	82.46	82.52	82.58	82.64	82.70	82.76	82.83	82.89	82.95	83.01
6,900	83.07	83.13	83.19	83.25	83.31	83.37	83.43	83.49	83.55	83.61
7,000	83.67	83.73	83.79	83.85	83.90	83.96	84.02	84.08	84.14	84.20
7,100	84.26	84.32	84.38	84.44	84.50	84.56	84.62	84.68	84.73	84.79
7,200	84.85	84.91	84.97	85.03	85.09	85.15	85.21	85.26	85.32	85.38
7,300	85.44	85.50	85.56	85.62	85.67	85.73	85.79	85.85	85.91	85.97
7,400	86.02	86.08	86.14	86.20	86.26	86.31	86.37	86.43	86.49	86.54
7,500	86.60	86.66	86.72	86.78	86.83	86.89	86.95	87.01	87.06	87.12
7,600	87.18	87.24	87.29	87.35	87.41	87.46	87.52	87.58	87.64	87.69
7,700	87.75	87.81	87.86	87.92	87.98	88.03	88.09	88.15	88.20	88.26
7,800	88.32	88.37	88.43	88.49	88.54	88.60	88.66	88.71	88.77	88.83
7,900	88.88	88.94	88.99	89.05	89.11	89.16	89.22	89.27	89.33	89.39
8,000	89.44	89.50	89.55	89.61	89.67	89.72	89.78	89.83	89.89	89.94
8,100	90.00	90.06	90.11	90.17	90.22	90.28	90.33	90.39	90.44	90.50
8,200	90.55	90.61	90.66	90.72	90.77	90.83	90.88	90.94	90.99	91.05
8,300	91.10	91.16	91.21	91.27	91.32	91.38	91.43	91.49	91.54	91.60
8,400	91.65	91.71	91.76	91.82	91.87	91.92	91.98	92.03	92.09	92.14
8,500	92.20	92.25	92.30	92.36	92.41	92.47	92.52	92.57	92.63	92.68
8,600	92.74	92.79	92.84	92.90	92.95	93.01	93.06	93.11	93.17	93.22
8,700	93.27	93.33	93.38	93.43	93.49	93.54	93.59	93.65	93.70	93.75
8,800	93.81	93.86	93.91	93.97	94.02	94.07	94.13	94.18	94.23	94.29
8,900	94.34	94.39	94.45	94.50	94.55	94.60	94.66	94.71	94.76	94.82
9,000	94.87	94.92	94.97	95.03	95.08	95.13	95.18	95.24	95.29	95.34
9,100	95.39	95.45	95.50	95.55	95.60	95.66	95.71	95.76	95.81	95.86
9,200	95.92	95.97	96.02	96.07	96.12	96.18	96.23	96.28	96.33	96.38
9,300	96.44	96.49	96.54	96.59	96.64	96.70	96.75	96.80	96.85	96.90
9,400	96.95	97.01	97.06	97.11	97.16	97.21	97.26	97.31	97.37	97.42
9,500	97.47	97.52	97.57	97.62	97.67	97.72	97.78	97.83	97.88	97.93
9,600	97.98	98.03	98.08	98.13	98.18	98.23	98.29	98.34	98.39	98.44
9,700	98.49	98.54	98.59	98.64	98.69	98.74	98.79	98.84	98.89	98.94
9,800	98.99	99.05	99.10	99.15	99.20	99.25	99.30	99.35	99.40	99.45
9,900	99.50	99.55	99.60	99.65	99.70	99.75	99.80	99.85	99.90	99.95

TABLE 98.—CIRCUMFERENCES OF CIRCLES BY HUNDREDTHS

Diam.	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
0.0	0.000	0.031	0.063	0.094	0.126	0.157	0.188	0.220	0.251	0.283
.1	0.314	0.346	0.377	0.408	0.440	0.471	0.503	0.534	0.565	0.597
.2	0.628	0.660	0.691	0.723	0.754	0.785	0.817	0.848	0.880	0.911
.3	0.942	0.974	1.005	1.037	1.068	1.100	1.131	1.162	1.194	1.225
.4	1.257	1.288	1.319	1.351	1.382	1.414	1.445	1.477	1.508	1.539
0.5	1.571	1.602	1.634	1.665	1.696	1.728	1.759	1.791	1.822	1.854
.6	1.885	1.916	1.948	1.979	2.011	2.042	2.073	2.105	2.136	2.168
.7	2.199	2.231	2.262	2.293	2.325	2.356	2.388	2.419	2.450	2.482
.8	2.513	2.545	2.576	2.608	2.639	2.670	2.702	2.733	2.765	2.796
.9	2.827	2.859	2.890	2.922	2.953	2.985	3.016	3.047	3.079	3.110
1.0	3.142	3.173	3.204	3.236	3.267	3.299	3.330	3.362	3.393	3.424
.1	3.456	3.487	3.519	3.550	3.581	3.613	3.644	3.676	3.707	3.738
.2	3.770	3.801	3.833	3.864	3.896	3.927	3.958	3.990	4.021	4.053
.3	4.084	4.115	4.147	4.178	4.210	4.241	4.273	4.304	4.335	4.367
.4	4.398	4.430	4.461	4.492	4.524	4.555	4.587	4.618	4.650	4.681
1.5	4.712	4.744	4.775	4.807	4.838	4.869	4.901	4.932	4.964	4.995
.6	5.027	5.058	5.089	5.121	5.152	5.184	5.215	5.246	5.278	5.309
.7	5.341	5.372	5.404	5.435	5.466	5.498	5.529	5.561	5.592	5.623
.8	5.655	5.686	5.718	5.749	5.781	5.812	5.843	5.875	5.906	5.938
.9	5.969	6.000	6.032	6.063	6.095	6.126	6.158	6.189	6.220	6.252
2.0	6.283	6.315	6.346	6.377	6.409	6.440	6.472	6.503	6.535	6.566
.1	6.597	6.629	6.660	6.692	6.723	6.754	6.786	6.817	6.849	6.880
.2	6.912	6.943	6.974	7.006	7.037	7.069	7.100	7.131	7.163	7.194
.3	7.226	7.257	7.288	7.320	7.351	7.383	7.414	7.446	7.477	7.508
.4	7.540	7.571	7.603	7.634	7.665	7.697	7.728	7.760	7.791	7.823
2.5	7.854	7.885	7.917	7.948	7.980	8.011	8.042	8.074	8.105	8.137
.6	8.168	8.200	8.231	8.262	8.294	8.325	8.357	8.388	8.419	8.451
.7	8.482	8.514	8.545	8.577	8.608	8.639	8.671	8.702	8.734	8.765
.8	8.796	8.828	8.859	8.891	8.922	8.954	8.985	9.016	9.048	9.079
.9	9.111	9.142	9.173	9.205	9.236	9.268	9.299	9.331	9.362	9.393
3.0	9.425	9.456	9.488	9.519	9.550	9.582	9.613	9.645	9.676	9.708
.1	9.739	9.770	9.802	9.833	9.865	9.896	9.927	9.959	9.990	10.022
.2	10.05	10.08	10.12	10.15	10.18	10.21	10.24	10.27	10.30	10.34
.3	10.37	10.40	10.43	10.46	10.49	10.52	10.56	10.59	10.62	10.65
.4	10.68	10.71	10.74	10.78	10.81	10.84	10.87	10.90	10.93	10.96
3.5	11.00	11.03	11.06	11.09	11.12	11.15	11.18	11.22	11.25	11.28
.6	11.31	11.34	11.37	11.40	11.44	11.47	11.50	11.53	11.56	11.59
.7	11.62	11.66	11.69	11.72	11.75	11.78	11.81	11.84	11.88	11.91
.8	11.94	11.97	12.00	12.03	12.06	12.10	12.13	12.16	12.19	12.22
.9	12.25	12.28	12.32	12.35	12.38	12.41	12.44	12.47	12.50	12.53
4.0	12.57	12.60	12.63	12.66	12.69	12.72	12.75	12.79	12.82	12.85
.1	12.88	12.91	12.94	12.97	13.01	13.04	13.07	13.10	13.13	13.16
.2	13.19	13.23	13.26	13.29	13.32	13.35	13.38	13.41	13.45	13.48
.3	13.51	13.54	13.57	13.60	13.63	13.67	13.70	13.73	13.76	13.79
.4	13.82	13.85	13.89	13.92	13.95	13.98	14.01	14.04	14.07	14.11
4.5	14.14	14.17	14.20	14.23	14.26	14.29	14.33	14.36	14.39	14.42
.6	14.45	14.48	14.51	14.55	14.58	14.61	14.64	14.67	14.70	14.73
.7	14.77	14.80	14.83	14.86	14.89	14.92	14.95	14.99	15.02	15.05
.8	15.08	15.11	15.14	15.17	15.21	15.24	15.27	15.30	15.33	15.36
.9	15.39	15.43	15.46	15.49	15.52	15.55	15.58	15.61	15.65	15.68

TABLE 98 (*Concluded*)

CIRCUMFERENCES OF CIRCLES BY HUNDREDTHS

Diam.	0	1	2	3	4	5	6	7	8	9
5.0	15.71	15.74	15.77	15.80	15.83	15.87	15.90	15.93	15.96	15.99
.1	16.02	16.05	16.08	16.12	16.15	16.18	16.21	16.24	16.27	16.30
.2	16.34	16.37	16.40	16.43	16.46	16.49	16.52	16.56	16.59	16.62
.3	16.65	16.68	16.71	16.74	16.78	16.81	16.84	16.87	16.90	16.93
.4	16.96	17.00	17.03	17.06	17.09	17.12	17.15	17.18	17.22	17.25
5.5	17.28	17.31	17.34	17.37	17.40	17.44	17.47	17.50	17.53	17.56
.6	17.59	17.62	17.66	17.69	17.72	17.75	17.78	17.81	17.84	17.88
.7	17.91	17.94	17.97	18.00	18.03	18.06	18.10	18.13	18.16	18.19
.8	18.22	18.25	18.28	18.32	18.35	18.38	18.41	18.44	18.47	18.50
.9	18.54	18.57	18.60	18.63	18.66	18.69	18.72	18.76	18.79	18.82
6.0	18.85	18.88	18.91	18.94	18.98	19.01	19.04	19.07	19.10	19.13
.1	19.16	19.20	19.23	19.26	19.29	19.32	19.35	19.38	19.42	19.45
.2	19.48	19.51	19.54	19.57	19.60	19.63	19.67	19.70	19.73	19.76
.3	19.79	19.82	19.85	19.89	19.92	19.95	19.98	20.01	20.04	20.07
.4	20.11	20.14	20.17	20.20	20.23	20.26	20.29	20.33	20.36	20.39
6.5	20.42	20.45	20.48	20.51	20.55	20.58	20.61	20.64	20.67	20.70
.6	20.73	20.77	20.80	20.83	20.86	20.89	20.92	20.95	20.99	21.02
.7	21.05	21.08	21.11	21.14	21.17	21.21	21.24	21.27	21.30	21.33
.8	21.36	21.39	21.43	21.46	21.49	21.52	21.55	21.58	21.61	21.65
.9	21.68	21.71	21.74	21.77	21.80	21.83	21.87	21.90	21.93	21.96
7.0	21.99	22.02	22.05	22.09	22.12	22.15	22.18	22.21	22.24	22.27
.1	22.31	22.34	22.37	22.40	22.43	22.46	22.49	22.53	22.56	22.59
.2	22.62	22.65	22.68	22.71	22.75	22.78	22.81	22.84	22.87	22.90
.3	22.93	22.97	23.00	23.03	23.06	23.09	23.12	23.15	23.18	23.22
.4	23.25	23.28	23.31	23.34	23.37	23.40	23.44	23.47	23.50	23.53
7.5	23.56	23.59	23.62	23.66	23.69	23.72	23.75	23.78	23.81	23.84
.6	23.88	23.91	23.94	23.97	24.00	24.03	24.06	24.10	24.13	24.16
.7	24.19	24.22	24.25	24.28	24.32	24.35	24.38	24.41	24.44	24.47
.8	24.50	24.54	24.57	24.60	24.63	24.66	24.69	24.72	24.76	24.79
.9	24.82	24.85	24.88	24.91	24.94	24.98	25.01	25.04	25.07	25.10
8.0	25.13	25.16	25.20	25.23	25.26	25.29	25.32	25.35	25.38	25.42
.1	25.45	25.48	25.51	25.54	25.57	25.60	25.64	25.67	25.70	25.73
.2	25.76	25.79	25.82	25.86	25.89	25.92	25.95	25.98	26.01	26.04
.3	26.08	26.11	26.14	26.17	26.20	26.23	26.26	26.30	26.33	26.36
.4	26.39	26.42	26.45	26.48	26.52	26.55	26.58	26.61	26.64	26.67
8.5	26.70	62.73	26.77	26.80	26.83	26.86	26.89	26.92	26.95	26.99
.6	27.02	27.05	27.08	27.11	27.14	27.17	27.21	27.24	27.27	27.30
.7	27.33	27.36	27.39	27.43	27.46	27.49	27.52	27.55	27.58	27.61
.8	27.65	27.68	27.71	27.74	27.77	27.80	27.83	27.87	27.90	27.93
.9	27.96	27.99	28.02	28.05	28.09	28.12	28.15	28.18	28.21	28.24
9.0	28.27	28.31	28.34	28.37	28.40	28.43	28.46	28.49	28.53	28.56
.1	28.59	28.62	28.65	28.68	28.71	28.75	28.78	28.81	28.84	28.87
.2	28.90	28.93	28.97	29.00	29.03	29.06	29.09	29.12	29.15	29.19
.3	29.22	29.25	29.28	29.31	29.34	29.37	29.41	29.44	29.47	29.50
.4	29.53	29.56	29.59	29.63	29.66	29.69	29.72	29.75	29.78	29.81
9.5	29.85	29.88	29.91	29.94	29.97	30.00	30.03	30.07	30.10	30.13
.6	30.16	30.19	30.22	30.25	30.28	30.32	30.35	30.38	30.41	30.44
.7	30.47	30.50	30.54	30.57	30.60	30.63	30.66	30.69	30.72	30.76
.8	30.79	30.82	30.85	30.88	30.91	30.94	30.98	31.01	31.04	31.07
.9	31.10	31.13	31.16	31.20	31.23	31.26	31.29	31.32	31.35	31.38

TABLE 99.—AREAS OF CIRCLES BY HUNDREDTHS

Diam.	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
0.0	0.000	0.000	0.000	0.001	0.001	0.002	0.003	0.004	0.005	0.006
0.1	0.008	0.010	0.011	0.013	0.015	0.018	0.020	0.023	0.025	0.028
0.2	0.031	0.035	0.038	0.042	0.045	0.049	0.053	0.057	0.062	0.066
0.3	0.071	0.075	0.080	0.086	0.091	0.096	0.102	0.108	0.113	0.119
0.4	0.126	0.132	0.139	0.145	0.152	0.159	0.166	0.173	0.181	0.189
0.5	0.196	0.204	0.212	0.221	0.229	0.238	0.246	0.255	0.264	0.273
0.6	0.283	0.292	0.302	0.312	0.322	0.332	0.342	0.353	0.363	0.374
0.7	0.385	0.396	0.407	0.419	0.430	0.442	0.454	0.466	0.478	0.490
0.8	0.503	0.515	0.528	0.541	0.554	0.567	0.581	0.594	0.608	0.622
0.9	0.636	0.650	0.665	0.679	0.694	0.709	0.724	0.739	0.754	0.770
1.0	0.785	0.801	0.817	0.833	0.849	0.866	0.882	0.899	0.916	0.933
1.1	0.950	0.968	0.985	1.003	1.021	1.039	1.057	1.075	1.094	1.112
1.2	1.131	1.150	1.169	1.188	1.208	1.227	1.247	1.267	1.287	1.307
1.3	1.327	1.348	1.368	1.389	1.410	1.431	1.453	1.474	1.496	1.517
1.4	1.539	1.561	1.584	1.606	1.629	1.651	1.674	1.697	1.720	1.744
1.5	1.767	1.791	1.815	1.839	1.863	1.887	1.911	1.936	1.961	1.986
1.6	2.011	2.036	2.061	2.087	2.112	2.138	2.164	2.190	2.217	2.243
1.7	2.270	2.297	2.324	2.351	2.378	2.405	2.433	2.461	2.488	2.516
1.8	2.545	2.573	2.602	2.630	2.659	2.688	2.717	2.746	2.776	2.806
1.9	2.835	2.865	2.895	2.926	2.956	2.986	3.017	3.048	3.079	3.110
2.0	3.142	3.173	3.205	3.237	3.269	3.301	3.333	3.365	3.398	3.431
2.1	3.464	3.497	3.530	3.563	3.597	3.631	3.664	3.698	3.733	3.767
2.2	3.801	3.836	3.871	3.906	3.941	3.976	4.011	4.047	4.083	4.119
2.3	4.155	4.191	4.227	4.264	4.301	4.337	4.374	4.412	4.449	4.486
2.4	4.524	4.562	4.600	4.638	4.676	4.714	4.753	4.792	4.831	4.870
2.5	4.909	4.948	4.988	5.027	5.067	5.107	5.147	5.187	5.228	5.269
2.6	5.309	5.350	5.391	5.433	5.474	5.515	5.557	5.599	5.641	5.683
2.7	5.726	5.768	5.811	5.853	5.896	5.940	5.983	6.026	6.070	6.114
2.8	6.158	6.202	6.246	6.290	6.335	6.379	6.424	6.469	6.514	6.560
2.9	6.605	6.651	6.697	6.743	6.789	6.835	6.881	6.928	6.975	7.022
3.0	7.069	7.116	7.163	7.211	7.258	7.306	7.354	7.402	7.451	7.499
3.1	7.548	7.596	7.645	7.694	7.744	7.793	7.843	7.892	7.942	7.992
3.2	8.042	8.093	8.143	8.194	8.245	8.296	8.347	8.398	8.450	8.501
3.3	8.553	8.605	8.657	8.709	8.762	8.814	8.867	8.920	8.973	9.026
3.4	9.079	9.133	9.186	9.240	9.294	9.348	9.402	9.457	9.511	9.566
3.5	9.62	9.68	9.73	9.79	9.84	9.90	9.95	10.01	10.07	10.12
3.6	10.18	10.24	10.29	10.35	10.41	10.46	10.52	10.58	10.64	10.69
3.7	10.75	10.81	10.87	10.93	10.99	11.04	11.10	11.16	11.22	11.28
3.8	11.34	11.40	11.46	11.52	11.58	11.64	11.70	11.76	11.82	11.88
3.9	11.95	12.01	12.07	12.13	12.19	12.25	12.32	12.38	12.44	12.50
4.0	12.57	12.63	12.69	12.76	12.82	12.88	12.95	13.01	13.07	13.14
4.1	13.20	13.27	13.33	13.40	13.46	13.53	13.59	13.66	13.72	13.79
4.2	13.85	13.92	13.99	14.05	14.12	14.19	14.25	14.32	14.39	14.45
4.3	14.52	14.59	14.66	14.73	14.79	14.86	14.93	15.00	15.07	15.14
4.4	15.21	15.27	15.34	15.41	15.48	15.55	15.62	15.69	15.76	15.83
4.5	15.90	15.98	16.05	16.12	16.19	16.26	16.33	16.40	16.47	16.55
4.6	16.62	16.69	16.76	16.84	16.91	16.98	17.06	17.13	17.20	17.28
4.7	17.35	17.42	17.50	17.57	17.65	17.72	17.80	17.87	17.95	18.02
4.8	18.10	18.17	18.25	18.32	18.40	18.47	18.55	18.63	18.70	18.78
4.9	18.86	18.93	19.01	19.09	19.17	19.24	19.32	19.40	19.48	19.56

Table 99 (*Concluded*)
Areas of Circles by Hundredths

Diam.	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
5.0	19.63	19.71	19.79	19.87	19.95	20.03	20.11	20.19	20.27	20.35
.1	20.43	20.51	20.59	20.67	20.75	20.83	20.91	20.99	21.07	21.16
.2	21.24	21.32	21.40	21.48	21.57	21.65	21.73	21.81	21.90	21.98
.3	22.06	22.15	22.23	22.31	22.40	22.48	22.56	22.65	22.73	22.82
.4	22.90	22.99	23.07	23.16	23.24	23.33	23.41	23.50	23.59	23.67
5.5	23.76	23.84	23.93	24.02	24.11	24.19	24.28	24.37	24.45	24.54
.6	24.63	24.72	24.81	24.89	24.98	25.07	25.16	25.25	25.34	25.43
.7	25.52	25.61	25.70	25.79	25.88	25.97	26.06	26.15	26.24	26.33
.8	26.42	26.51	26.60	26.69	26.79	26.88	26.97	27.06	27.15	27.25
.9	27.34	27.43	27.53	27.62	27.71	27.81	27.90	27.99	28.09	28.18
6.0	28.27	28.37	28.46	28.56	28.65	28.75	28.84	28.94	29.03	29.13
.1	29.22	29.32	29.42	29.51	29.61	29.71	29.80	29.90	30.00	30.09
.2	30.19	30.29	30.39	30.48	30.58	30.68	30.78	30.88	30.97	31.07
.3	31.17	31.27	31.37	31.47	31.57	31.67	31.77	31.87	31.97	32.07
.4	32.17	32.27	32.37	32.47	32.57	32.67	32.78	32.88	32.98	33.08
6.5	33.18	33.29	33.39	33.49	33.59	33.70	33.80	33.90	34.00	34.11
.6	34.21	34.32	34.42	34.52	34.63	34.73	34.84	34.94	35.05	35.15
.7	35.26	35.36	35.47	35.57	35.68	35.78	35.89	36.00	36.10	36.21
.8	36.32	36.42	36.53	36.64	36.75	36.85	36.96	37.07	37.18	37.28
.9	37.39	37.50	37.61	37.72	37.83	37.94	38.05	38.16	38.26	38.37
7.0	38.48	38.59	38.70	38.82	38.93	39.04	39.15	39.26	39.37	39.48
.1	39.59	39.70	39.82	39.93	40.04	40.15	40.26	40.38	40.49	40.60
.2	40.72	40.83	40.94	41.06	41.17	41.28	41.40	41.51	41.62	41.74
.3	41.85	41.97	42.08	42.20	42.31	42.43	42.54	42.66	42.78	42.89
.4	43.01	43.12	43.24	43.36	43.47	43.59	43.71	43.83	43.94	44.06
7.5	44.18	44.30	44.41	44.53	44.65	44.77	44.89	45.01	45.13	45.25
.6	45.36	45.48	45.60	45.72	45.84	45.96	46.08	46.20	46.32	46.45
.7	46.57	46.69	46.81	46.93	47.05	47.17	47.29	47.42	47.54	47.66
.8	47.78	47.91	48.03	48.15	48.27	48.40	48.52	48.65	48.77	48.89
.9	49.02	49.14	49.27	49.39	49.51	49.64	49.76	49.89	50.01	50.14
8.0	50.27	50.39	50.52	50.64	50.77	50.90	51.02	51.15	51.28	51.40
.1	51.53	51.66	51.78	51.91	52.04	52.17	52.30	52.42	52.55	52.68
.2	52.81	52.94	53.07	53.20	53.33	53.46	53.59	53.72	53.85	53.98
.3	54.11	54.24	54.37	54.50	54.63	54.76	54.89	55.02	55.15	55.29
.4	55.42	55.55	55.68	55.81	55.95	56.08	56.21	56.35	56.48	56.61
8.5	56.75	56.88	57.01	57.15	57.28	57.41	57.55	57.68	57.82	57.95
.6	58.09	58.22	58.36	58.49	58.63	58.77	58.90	59.04	59.17	59.31
.7	59.45	59.58	59.72	59.86	59.99	60.13	60.27	60.41	60.55	60.68
.8	60.82	60.96	61.10	61.24	61.38	61.51	61.65	61.79	61.93	62.07
.9	62.21	62.35	62.49	62.63	62.77	62.91	63.05	63.19	63.33	63.48
9.0	63.62	63.76	63.90	64.04	64.18	64.33	64.47	64.61	64.75	64.90
.1	65.04	65.18	65.33	65.47	65.61	65.76	65.90	66.04	66.19	66.33
.2	66.48	66.62	66.77	66.91	67.06	67.20	67.35	67.49	67.64	67.78
.3	67.93	68.08	68.22	68.37	68.51	68.66	68.81	68.96	69.10	69.25
.4	69.40	69.55	69.69	69.84	69.99	70.14	70.29	70.44	70.58	70.73
9.5	70.88	71.03	71.18	71.33	71.48	71.63	71.78	71.93	72.08	72.23
.6	72.38	72.53	72.68	72.84	72.99	73.14	73.29	73.44	73.59	73.75
.7	73.90	74.05	74.20	74.36	74.51	74.66	74.82	74.97	75.12	75.28
.8	75.43	75.58	75.74	75.89	76.05	76.20	76.36	76.51	76.67	76.82
.9	76.98	77.13	77.29	77.44	77.60	77.76	77.91	78.07	78.23	78.38

TABLE 100.—CIRCUMFERENCES OF CIRCLES BY EIGHTHS

Diam.	0	1/8	1/4	3/8	1/2	5/8	3/4	7/8
0	.0000	.3927	.7854	1.178	1.571	1.963	2.356	2.749
1	3.142	3.534	3.927	4.320	4.712	5.105	5.498	5.890
2	6.233	6.676	7.069	7.461	7.854	8.247	8.639	9.032
3	9.425	9.817	10.21	10.60	11.00	11.39	11.78	12.17
4	12.57	12.96	13.35	13.74	14.14	14.53	14.92	15.32
5	15.71	16.10	16.49	16.89	17.28	17.67	18.06	18.46
6	18.85	19.24	19.63	20.03	20.42	20.81	21.21	21.60
7	21.99	22.38	22.78	23.17	23.56	23.95	24.35	24.74
8	25.13	25.53	25.92	26.31	26.70	27.10	27.49	27.88
9	28.27	28.67	29.06	29.45	29.85	30.24	30.63	31.02
10	31.42	31.81	32.20	32.59	32.99	33.38	33.77	34.16
1	34.56	34.95	35.34	35.74	36.13	36.52	36.91	37.31
2	37.70	38.09	38.48	38.88	39.27	39.66	40.06	40.45
3	40.84	41.23	41.63	42.02	42.41	42.80	43.20	43.59
4	43.98	44.37	44.77	45.16	45.55	45.95	46.34	46.73
15	47.12	47.52	47.91	48.30	48.69	49.09	49.48	49.87
6	50.27	50.66	51.05	51.44	51.84	52.23	52.62	53.01
7	53.41	53.80	54.19	54.59	54.98	55.37	55.76	56.16
8	56.55	56.94	57.33	57.73	58.12	58.51	58.90	59.30
9	59.69	60.08	60.48	60.87	61.26	61.65	62.05	62.44
20	62.83	63.22	63.62	64.01	64.40	64.80	65.19	65.58
1	65.97	66.37	66.76	67.15	67.54	67.94	68.33	68.72
2	69.12	69.51	69.90	70.29	70.69	71.08	71.47	71.86
3	72.26	72.65	73.04	73.43	73.83	74.22	74.61	75.01
4	75.40	75.79	76.18	76.58	76.97	77.36	77.75	78.15
25	78.54	78.93	79.33	79.72	80.11	80.50	80.90	81.29
6	81.68	82.07	82.47	82.86	83.25	83.64	84.04	84.43
7	84.82	85.22	85.61	86.00	86.39	86.79	87.18	87.57
8	87.96	88.36	88.75	89.14	89.54	89.93	90.32	90.71
9	91.11	91.50	91.89	92.28	92.68	93.07	93.46	93.86
30	94.25	94.64	95.03	95.43	95.82	96.21	96.60	97.00
1	97.39	97.78	98.17	98.57	98.96	99.35	99.75	100.1
2	100.5	100.9	101.3	101.7	102.1	102.5	102.9	103.3
3	103.7	104.1	104.5	104.9	105.2	105.6	106.0	106.4
4	106.8	107.2	107.6	108.0	108.4	108.8	109.2	109.6
35	110.0	110.3	110.7	111.1	111.5	111.9	112.3	112.7
6	113.1	113.5	113.9	114.3	114.7	115.1	115.5	115.8
7	116.2	116.6	117.0	117.4	117.8	118.2	118.6	119.0
8	119.4	119.8	120.2	120.6	121.0	121.3	121.7	122.1
9	122.5	122.9	123.3	123.7	124.1	124.5	124.9	125.3
40	125.7	126.1	126.4	126.8	127.2	127.6	128.0	128.4
1	128.8	129.2	129.6	130.0	130.4	130.8	131.2	131.6
2	131.9	132.3	132.7	133.1	133.5	133.9	134.3	134.7
3	135.1	135.5	135.9	136.3	136.7	137.1	137.4	137.8
4	138.2	138.6	139.0	139.4	139.8	140.2	140.6	141.0
45	141.4	141.8	142.2	142.5	142.9	143.3	143.7	144.1
6	144.5	144.9	145.3	145.7	146.1	146.5	146.9	147.3
7	147.7	148.0	148.4	148.8	149.2	149.6	150.0	150.4
8	150.8	151.2	151.6	152.0	152.4	152.8	153.2	153.5
9	153.9	154.3	154.7	155.1	155.5	155.9	156.3	156.7

TABLE 100 (*Concluded*)

CIRCUMFERENCES OF CIRCLES BY EIGHTHS

Diam.	0	⅛	¼	⅜	½	⅝	¾	⅞
50	157.1	157.5	157.9	158.3	158.7	159.0	159.4	159.8
1	160.2	160.6	161.0	161.4	161.8	162.2	162.6	163.0
2	163.4	163.8	164.1	164.5	164.9	165.3	165.7	166.1
3	166.5	166.9	167.3	167.7	168.1	168.5	168.9	169.3
4	169.6	170.0	170.4	170.8	171.2	171.6	172.0	172.4
55	172.8	173.2	173.6	174.0	174.4	174.8	175.1	175.5
6	175.9	176.3	176.7	177.1	177.5	177.9	178.3	178.7
7	179.1	179.5	179.9	180.2	180.6	181.0	181.4	181.8
8	182.2	182.6	183.0	183.4	183.8	184.2	184.6	185.0
9	185.4	185.7	186.1	186.5	186.9	187.3	187.7	188.1
60	188.5	188.9	189.3	189.7	190.1	190.5	190.9	191.2
1	191.6	192.0	192.4	192.8	193.2	193.6	194.0	194.4
2	194.8	195.2	195.6	196.0	196.3	196.7	197.1	197.5
3	197.9	198.3	198.7	199.1	199.5	199.9	200.3	200.7
4	201.1	201.5	201.8	202.2	202.6	203.0	203.4	203.8
65	204.2	204.6	205.0	205.4	205.8	206.2	206.6	207.0
6	207.3	207.7	208.1	208.5	208.9	209.3	209.7	210.1
7	210.5	210.9	211.3	211.7	212.1	212.5	212.8	213.2
8	213.6	214.0	214.4	214.8	215.2	215.6	216.0	216.4
9	216.8	217.2	217.6	217.9	218.3	218.7	219.1	219.5
70	219.9	220.3	220.7	221.1	221.5	221.9	222.3	222.7
1	223.1	223.4	223.8	224.2	224.6	225.0	225.4	225.8
2	226.2	226.6	227.0	227.4	227.8	228.2	228.6	228.9
3	229.3	229.7	230.1	230.5	230.9	231.3	231.7	232.1
4	232.5	232.9	233.3	233.7	234.0	234.4	234.8	235.2
75	235.6	236.0	236.4	236.8	237.2	237.6	238.0	238.4
6	238.8	239.2	239.5	239.9	240.3	240.7	241.1	241.5
7	241.9	242.3	242.7	243.1	243.5	243.9	244.3	244.7
8	245.0	245.4	245.8	246.2	246.6	247.0	247.4	247.8
9	248.2	248.6	249.0	249.4	249.8	250.1	250.5	250.9
80	251.3	251.7	252.1	252.5	252.9	253.3	253.7	254.1
1	254.5	254.9	255.3	255.6	256.0	256.4	256.8	257.2
2	257.6	258.0	258.4	258.8	259.2	259.6	260.0	260.4
3	260.8	261.1	261.5	261.9	262.3	262.7	263.1	263.5
4	263.9	264.3	264.7	265.1	265.5	265.9	266.2	266.6
85	267.0	267.4	267.8	268.2	268.6	269.0	269.4	269.8
6	270.2	270.6	271.0	271.4	271.7	272.1	272.5	272.9
7	273.3	273.7	274.1	274.5	274.9	275.3	275.7	276.1
8	276.5	276.9	277.2	277.6	278.0	278.4	278.8	279.2
9	279.6	280.0	280.4	280.8	281.2	281.6	282.0	282.4
90	282.7	283.1	283.5	283.9	284.3	284.7	285.1	285.5
1	285.9	286.3	286.7	287.1	287.5	287.8	288.2	288.6
2	289.0	289.4	289.8	290.2	290.6	291.0	291.4	291.8
3	292.2	292.6	293.0	293.3	293.7	294.1	294.5	294.9
4	295.3	295.7	296.1	296.5	296.9	297.3	297.7	298.1
95	298.5	298.8	299.2	299.6	300.0	300.4	300.8	301.2
6	301.6	302.0	302.4	302.8	303.2	303.6	303.9	304.3
7	304.7	305.1	305.5	305.9	306.3	306.7	307.1	307.5
8	307.9	308.3	308.7	309.1	309.4	309.8	310.2	310.6
9	311.0	311.4	311.8	312.2	312.6	313.0	313.4	313.8

Table 101.—Areas of Circles by Eighths

Diam.	0	1/8	1/4	3/8	1/2	5/8	3/4	7/8
0	.0000	.0123	.0491	.1104	.1963	.3068	4.418	.6013
1	.7854	.9940	1.227	1.485	1.767	2.074	2.405	2.761
2	3.142	3.547	3.976	4.430	4.909	5.412	5.940	6.492
3	7.069	7.670	8.296	8.946	9.621	10.32	11.04	11.79
4	12.57	13.36	14.19	15.03	15.90	16.80	17.72	18.67
5	19.63	20.63	21.65	22.69	23.76	24.85	25.97	27.11
6	28.27	29.47	30.68	31.92	33.18	34.47	35.78	37.12
7	38.48	39.87	41.28	42.72	44.18	45.66	47.17	48.71
8	50.27	51.85	53.46	55.09	56.75	58.43	60.13	61.86
9	63.62	65.40	67.20	69.03	70.88	72.76	74.66	76.59
10	78.54	80.52	82.52	84.54	86.59	88.66	90.76	92.89
1	95.03	97.21	99.40	101.6	103.9	106.1	108.4	110.8
2	113.1	115.5	117.9	120.3	122.7	125.2	127.7	130.2
3	132.7	135.3	137.9	140.5	143.1	145.8	148.5	151.2
4	153.9	156.7	159.5	162.3	165.1	168.0	170.9	173.8
15	176.7	179.7	182.7	185.7	188.7	191.7	194.8	197.9
6	201.1	204.2	207.4	210.6	213.8	217.1	220.4	223.7
7	227.0	230.3	233.7	237.1	240.5	244.0	247.4	250.9
8	254.5	258.0	261.6	265.2	268.8	272.4	276.1	279.8
9	283.5	287.3	291.0	294.8	298.6	302.5	306.4	310.2
20	314.2	318.1	322.1	326.1	330.1	334.1	338.2	342.2
1	346.4	350.5	354.7	358.8	363.1	367.3	371.5	375.8
2	380.1	384.5	388.8	393.2	397.6	402.0	406.5	411.0
3	415.5	420.0	424.6	429.1	433.7	438.4	443.0	447.7
4	452.4	457.1	461.9	466.6	471.4	476.3	481.1	486.0
25	490.9	495.8	500.7	505.7	510.7	515.7	520.8	525.8
6	530.9	536.0	541.2	546.4	551.5	556.8	562.0	567.3
7	572.6	577.9	583.2	588.6	594.0	599.4	604.8	610.3
8	615.8	621.3	626.8	632.4	637.9	643.5	649.2	654.8
9	660.5	666.2	672.0	677.7	683.5	689.3	695.1	701.0
30	706.9	712.8	718.7	724.6	730.6	736.6	742.6	748.7
1	754.8	760.9	767.0	773.1	779.3	785.5	791.7	798.0
2	804.2	810.5	816.9	823.2	829.6	836.0	842.4	848.8
3	855.3	861.8	868.3	874.8	881.4	888.0	894.6	901.3
4	907.9	914.6	921.3	928.1	934.8	941.6	948.4	955.3
35	962.1	969.0	975.9	982.8	989.8	996.8	1004	1011
6	1018	1025	1032	1039	1046	1054	1061	1068
7	1075	1082	1090	1097	1104	1112	1119	1127
8	1134	1142	1149	1157	1164	1172	1179	1187
9	1195	1202	1210	1218	1225	1233	1241	1249
40	1257	1265	1272	1280	1288	1296	1304	1312
1	1320	1328	1336	1345	1353	1361	1369	1377
2	1385	1394	1402	1410	1419	1427	1435	1444
3	1452	1461	1469	1478	1486	1495	1503	1512
4	1521	1529	1538	1547	1555	1564	1573	1582
45	1590	1599	1608	1617	1626	1635	1644	1653
6	1662	1671	1680	1689	1698	1707	1717	1726
7	1735	1744	1753	1763	1772	1781	1791	1800
8	1810	1819	1828	1838	1847	1857	1867	1876
9	1886	1895	1905	1915	1924	1934	1944	1954

Table 101 (*Concluded*)

Areas of Circles by Eighths

Diam.	0	⅛	¼	⅜	½	⅝	¾	⅞
50	1963	1973	1983	1993	2003	2013	2023	2033
1	2043	2053	2063	2073	2083	2093	2103	2114
2	2124	2134	2144	2154	2165	2175	2185	2196
3	2206	2217	2227	2238	2248	2259	2269	2280
4	2290	2301	2311	2322	2333	2344	2354	2365
55	2376	2387	2397	2408	2419	2430	2441	2452
6	2463	2474	2485	2496	2507	2518	2529	2541
7	2552	2563	2574	2585	2597	2608	2619	2631
8	2642	2653	2665	2676	2688	2699	2711	2722
9	2734	2746	2757	2769	2781	2792	2804	2816
60	2827	2839	2851	2863	2875	2887	2899	2911
1	2922	2934	2946	2959	2971	2983	2995	3007
2	3019	3031	3043	3056	3068	3080	3093	3105
3	3117	3130	3142	3154	3167	3179	3192	3204
4	3217	3230	3242	3255	3267	3280	3293	3306
65	3318	3331	3344	3357	3370	3382	3395	3408
6	3421	3434	3447	3460	3473	3486	3499	3513
7	3526	3539	3552	3565	3578	3592	3605	3618
8	3632	3645	3658	3672	3685	3699	3712	3726
9	3739	3753	3766	3780	3794	3807	3821	3835
70	3848	3862	3876	3890	3904	3917	3931	3945
1	3959	3973	3987	4001	4015	4029	4043	4057
2	4072	4086	4100	4114	4128	4142	4157	4171
3	4185	4200	4214	4228	4243	4257	4272	4286
4	4301	4315	4330	4345	1359	4374	4388	4403
75	4418	4433	4447	4462	4477	4492	4507	4522
6	4536	4551	4566	4581	4596	4611	4626	4642
7	4657	4672	4687	4702	4717	4733	4748	4763
8	4778	4794	4809	4824	4840	4855	4871	4886
9	4902	4917	4933	4948	4964	4980	4995	5011
80	5027	5042	5058	5074	5090	5105	5121	5137
1	5153	5169	5185	5201	5217	5233	5249	5265
2	5281	5297	5313	5329	5346	5362	5378	5394
3	5411	5427	5443	5460	5476	5492	5509	5525
4	5542	5558	5575	5591	5608	5625	5641	5658
85	5675	5691	5708	5725	5741	5758	5775	5792
6	5809	5826	5843	5860	5877	5894	5911	5928
7	5945	5962	5979	5996	6013	6030	6048	6065
8	6082	6099	6117	6134	6151	6169	6186	6204
9	6221	6239	6256	6274	6291	6309	6326	6344
90	6362	6379	6397	6415	6433	6450	6468	6486
1	6504	6522	6540	6558	6576	6594	6612	6630
2	6648	6666	6684	6702	6720	6738	6756	6775
3	6793	6811	6829	6848	6866	6885	6903	6921
4	6940	6958	6977	6995	7014	7032	7051	7070
95	7088	7107	7126	7144	7163	7182	7201	7219
6	7238	7257	7276	7295	7314	7333	7352	7371
7	7390	7409	7428	7447	7466	7485	7505	7524
8	7543	7562	7581	7601	7620	7639	7659	7678
9	7698	7717	7737	7756	7776	7795	7815	7834

APPENDIX A

COMPARISON OF WEIR FORMULAS WITH EXPERIMENTS

Inasmuch as the author is advocating a new weir formula for sharp-crested weirs with free overfall and also a new formula for submerged weirs it appears advisable to submit the data on which these formulas are based.

In the following pages the formulas and experiments of Francis, Fteley and Stearns, and Bazin are investigated. Tables and diagrams are given which show the extent to which these formulas and the author's formulas (formula (7) or (7*a*), page 72, for weirs with free overfall and formula (41), page 82, for submerged weirs, agree with the experiments. The following discussion should be read in connection with that given on pages 63 to 84.

Application of Formula to Suppressed Weirs

The Bazin Experiments.—The most complete set of experiments on suppressed weirs are those of Bazin. Table 102 has been prepared to show how the author's formula for weirs with free overfall and some of the more commonly used weir formulas agree with Bazin's experiments. This table covers practically the entire range of these experiments, the heights of weir varying from 0.79 to 3.72 feet. with a range of head of from 0.2 to 1.4 feet.

In column 5 of this table are given Bazin's experimental discharges. These values were computed by using Bazin's diagram[1] of coefficients which gives the mean of his experimental results. Columns 6 and 7 give discharges by the Bazin formula and the author's formula respectively. Discharges obtained by other methods are also given as follows: In column 8 by the Lyman diagram, in column 9 by the Francis formula, in

[1] Plate 22, *Annales des Ponts et Chaussees*, October, 1888.

column 10 by the Fteley and Stearns formula and in column 11 by formula (2); the latter will be explained later (page 389).

It will be observed that in general the author's formula comes somewhat closer to the experimental values than any of the other formulas. Bazin's formula and Lyman's diagram also agree very well with the experimental values. The Lyman diagram was based upon measurements made 15 feet upstream from the weir by means of a plummet suspended by a tape, and a correction was made to the Bazin experiments to make them conform to this method of measurement. This doubtless accounts in a measure at least for the discrepancies in these results. The discharges by the Fteley and Stearns formula are in general less than the experimental results but they exceed them for the higher heads on the weir 0.79 feet high and approach them again for the weir 3.72 feet high. This indicates the need of a varying coefficient to be applied to a formula of this kind. The Francis formula shows a wide variance from these experimental results. It compares more favorably for the highest weir, however, which is what would be expected since the Francis formula is based upon experiments with higher weirs than the Bazin formula.

The author's formula agrees with the experimental results especially well for the lower heads. It is here that investigators have generally had difficulty in deriving a formula that would give discharges sufficiently great without departing too far from the experiments for higher heads.

Fig. 89 shows graphically the discrepancies resulting from Table 102. The experimental values are shown on the straight line which is used as a base. The discrepancies of the formulas from these values for different heads are indicated by the broken lines. The comparative results by the various formulas can be readily seen from this figure.

Table 103 has been prepared from Fig. 89 by determining the areas between each of the broken lines and the base line. Areas above the base are indicated as plus and those below minus. The figures are not definite quantities but represent the comparative discrepancies for each formula. The last four columns show a summary of the results, the last column giving the comparative total discrepancies both plus and minus. From these figures it will be seen that the author's formula agrees a little closer with the Bazin experiments than any of the other formulas.

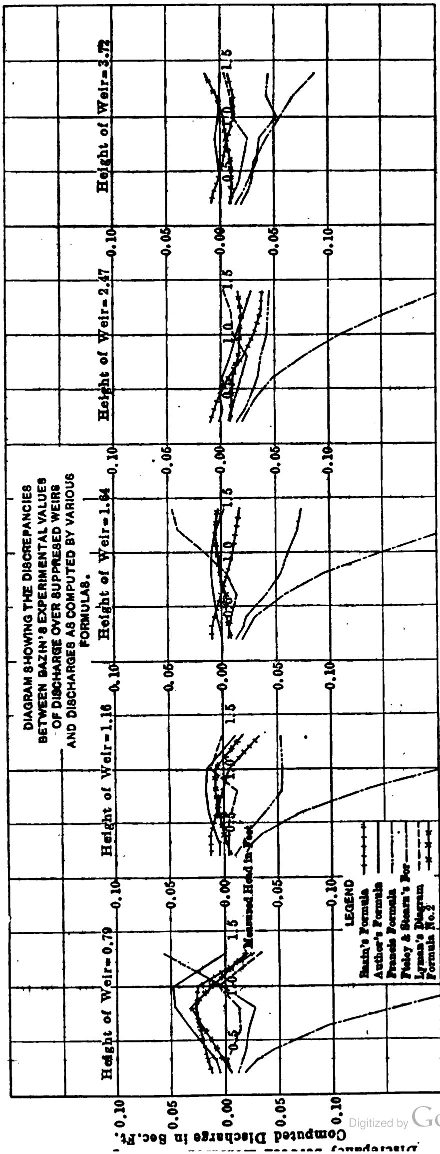


DIAGRAM SHOWING THE DISCREPANCIES BETWEEN BAZIN'S EXPERIMENTAL VALUES OF DISCHARGE OVER SUPPRESED WEIRS AND DISCHARGES AS COMPUTED BY VARIOUS FORMULAS.
Height of Weir = 0.79
Height of Weir = 1.16
Height of Weir = 1.64
Height of Weir = 2.47
Height of Weir = 3.72
Measured Head in Feet
LEGEND
Bazin's Formula
Author's Formula
Francis Formula
Fteley & Stearn's For.
Lyman's Diagram
Formula No.2
Computed Discharge in Sec.Ft.
0.10
0.05
0.00
0.05
0.10
0.5
1.0
1.5

FIG. 89.

TABLE 102.—SHOWING COMPARATIVE VALUES OF DISCHARGE OVER SUPPRESSED WEIRS AS DETERMINED FROM BAZIN'S EXPERIMENTS AND AS COMPUTED BY VARIOUS WEIR FORMULAS

Height of weir	Measured head	Area of channel of approach divided by length of weir	Velocity of approach	Experimental discharge	Discharge by Bazin formula	Discharge by author's formula	Discharge by Lyman diagram	Discharge by Francis formula	Discharge by Fteley & Stearns formula	Discharge by formula (2)
P	*H*	*d*	*V*	*Q*	*Q*	*Q*	*Q*	*Q*	*Q*	*Q*
1	2	3	4	5	6	7	8	9	10	11
0.79	0.2	0.99	.33	.320	.333	.325	.314	.302	.308	.315
	0.3	1.09	.54	.585	.601	.593	.583	.557	.570	.585
	0.4	1.19	.76	.908	.926	.923	.903	.866	.889	.914
	0.6	1.39	1.23	1.710	1.732	1.741	1.696	1.620	1.682	1.729
	0.8	1.59	1.70	2.701	2.728	2.747	2.688	2.533	2.679	2.733
	1.0	1.79	2.17	3.876	3.900	3.924	3.881	3.590	3.878	3.887
	1.3	2.09	2.86	5.977	5.949	5.976	5.943	5.410	6.033	5.956
1.16	0.2	1.36	.23	.319	.330	.322	.313	.299	.308	.312
	0.3	1.46	.40	.579	.590	.582	.574	.553	.561	.575
	0.4	1.56	.57	.892	.903	.899	.887	.856	.870	.891
	0.6	1.76	.94	1.665	1.672	1.679	1.658	1.593	1.627	1.669
	0.8	1.96	1.33	2.614	2.614	2.630	2.600	2.481	2.560	2.621
	1.0	2.16	1.73	3.726	3.720	3.741	3.737	3.507	3.671	3.733
	1.3	2.46	2.31	5.694	5.660	5.682	5.695	5.280	5.338	5.675
	1.5	2.66	2.68	.....	7.126	7.141	.....	6.603	7.138	
	2.0	3.16	3.59	.....	11.350	11.329	.....	10.361	11.560	
	3.0	4.16	5.27	.....	21.896	21.694	.....	20.226	23.069	
	4.0	5.16	6.57	.....	34.780	34.251	.....	31.787	37.092	
1.64	0.2	1.84	.17	.319	.328	.320	.312	.299	.305	.310
	0.3	1.94	.30	.576	.585	.577	.569	.550	.556	.569
	0.4	2.04	.44	.883	.890	.887	.874	.852	.860	.878
	0.6	2.24	.73	1.633	1.633	1.640	1.619	1.575	1.592	1.630
	0.8	2.44	1.04	2.542	2.537	2.551	2.536	2.446	2.487	2.543
	1.0	2.64	1.37	3.601	3.590	3.609	3.616	3.449	3.539	3.604
	1.2	2.84	1.69	4.799	4.785	4.804	4.838	4.573	4.728	4.804
	1.4	3.04	2.02	6.132	6.115	6.129	6.177	5.808	6.057	6.134
	2.0	3.64	2.98	.....	10.846	10.814	.....	10.126	10.860	
	3.0	4.64	4.51	.....	20.934	20.729	.....	19.118	21.439	
	4.0	5.64	5.92	.....	33.376	32.847	.....	30.926	35.001	

Table 102 (*Concluded*)

Showing Comparative Values of Discharge over Suppressed Weirs as Determined from Bazin's Experiments and as Computed by Various Weir Formulas

Height of weir	Measured head	Area of channel of approach divided by length of weir	Velocity of approach	Experimental discharge	Discharge by Bazin formula	Discharge by author's formula	Discharge by Lyman diagram	Discharge by Francis formula	Discharge by Fteley & Stearns formula	Discharge by formula (2)
P	*H*	*d*	*V*	*Q*	*Q*	*Q*	*Q*	*Q*	*Q*	*Q*
1	2	3	4	5	6	7	8	9	10	11
2.47	0.2	2.67	.12	.318	.327	.319	.311	.298	.303	.309
	0.3	2.77	.21	.575	.581	.573	.565	.549	.554	.565
	0.4	2.87	.31	.878	.881	.878	.865	.847	.851	.868
	0.6	3.07	.52	1.611	1.604	1.610	1.592	1.563	1.569	1.600
	0.8	3.27	.76	2.495	2.474	2.486	2.470	2.418	2.433	2.478
	1.0	3.47	1.01	3.510	3.479	3.495	3.498	3.399	3.437	3.492
	1.2	3.67	1.27	4.650	4.613	4.628	4.640	4.493	4.550	4.631
	1.4	3.87	1.53	5.908	5.869	5.879	5.905	5.695	5.810	5.892
	2.0	4.47	2.30	.....	10.325	10.289	.....	9.888	10.246	
	3.0	5.47	3.59	.....	19.833	19.618	.....	18.592	19.850	
	4.0	6.47	4.81	.....	31.637	31.113	.....	29.171	32.016	
	5.0	7.47	5.95	.....	45.497	44.509	.....	41.389	46.529	
3.72	0.2	3.92	.08	.318	.326	.318	.309	.298	.303	.308
	0.3	4.02	.14	.573	.579	.571	.561	.548	.551	.562
	0.4	4.12	.21	.874	.876	.873	.856	.845	.848	.863
	0.6	4.32	.37	1.591	1.588	1.593	1.569	1.559	1.557	1.582
	0.8	4.52	.54	2.444	2.437	2.448	2.418	2.401	2.407	2.439
	1.0	4.72	.72	3.423	3.410	3.424	3.411	3.367	3.370	3.420
	1.2	4.92	.92	4.511	4.499	4.512	4.502	4.442	4.467	4.515
	1.4	5.12	1.11	5.706	5.699	5.705	5.702	5.618	5.661	5.720
	2.0	5.72	1.73	.....	9.923	9.884	.....	9.704	9.865	
	3.0	6.72	2.81	.....	18.878	18.667	.....	18.160	18.806	
	4.0	7.72	3.88	.....	30.006	29.485	.....	28.416	30.041	
	5.0	8.72	4.94	.....	43.088	42.133	.....	40.264	43.500	

TABLE 103.—SHOWING COMPARATIVE DISCREPANCIES BETWEEN BAZIN'S EXPERIMENTAL VALUES OF DISCHARGE OVER SUPPRESSED WEIRS AND DISCHARGES AS COMPUTED BY VARIOUS FORMULAS

Name of formula	Height of weir										Total +	Total −	Sum of differences	Total + & −
	0.79		1.16		1.64		2.47		3.72					
	Discrepancy													
	+	−	+	−	+	−	+	−	+	−				
Bazin.....	74	9	22	29	9	32	5	91	5	29	115	190	−75	305
Author's formula..	123	...	40	2	28	...	..	50	6	...	197	52	+145	249
Lyman's diagram..	1	45	9	21	58	21	..	68	..	76	68	231	−163	299
Fteley & Stearns..	34	59	..	185	..	237	..	173	..	180	34	844	−810	878
Francis'...	...	524	..	409	..	579	..	440	..	227	.....	2,179	−2,179	2,179
Formula (2)......	50	9	11	12	8	9	..	73	8	27	77	130	−53	207

+ indicates area under curve above base line.
− indicates area under curve below base line.

The Fteley and Stearns Experiments.—These experiments were made with two weirs 5 feet and 19 feet long and 3.17 feet and 6.55 feet high respectively. Table 104, Fig. 90, and Table 105 have been prepared to show the discrepancies between the Fteley and Stearns experiments and various formulas. The values given in column 6 of Table 104 were obtained graphically by plotting all of the Fteley and Stearns experiments with Q per linear foot and H as coördinates. The discharges for the heads given in the table were taken directly from the curve. The scale was so chosen that discharges could be read to thousandths of a cubic foot per second.

The Fteley and Stearns formula agrees closest with these experiments. The author's formula and the Bazin formula give results greater than the experimental values. The Bazin experiments are not consistent with those of Fteley and Stearns, as can be seen by comparing results of the former, interpolated between weirs 2.47 and 3.72 feet high, with results of the latter for the weir 3.17 feet high. It is therefore impossible to have any formula agree closely with both sets of experiments. The maximum divergence occurs with the weir 19 feet long where the author's formula gives some results about 0.04 cubic feet

per second too great. It will be observed from Fig. 90 that the curve of variance of the author's formula is nearly parallel to that of the Bazin formula. It is to be hoped that additional experiments will soon be available to clear up the apparent inconsistencies in the experiments of Bazin and Fteley and Stearns (see discussion, page 402).

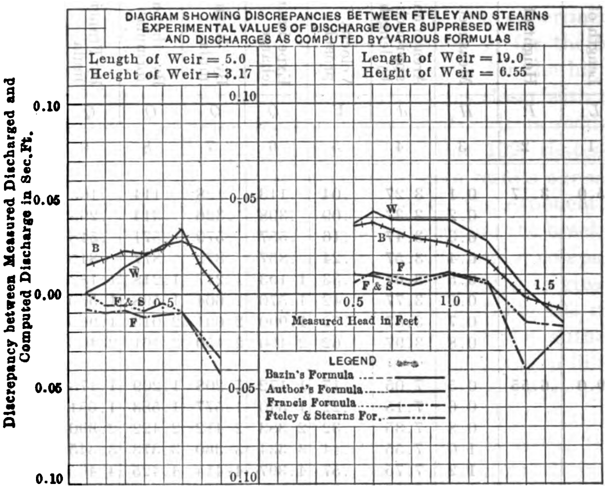


FIG. 90.

Verification of Formula

In order to determine whether the author's formula will fit the experimental data as satisfactorily as any other formula of this type the general equation

$$Q = ALH^m\left[1 + B\left(\frac{H}{d}\right)^n\right] \qquad (1)$$

was investigated and compared with the author's formula by the laborious process of least squares. The formula determined from the data in Table 102 as the one fulfilling the requirement that the sum of the squares of the residual errors shall be a minimum is

$$Q = 3.33LH^{1.48}\left[1 + 0.53\left(\frac{H}{d}\right)^{1.92}\right] \qquad (2)$$

Table 104.—Showing Comparative Values of Discharge over Suppressed Weirs as Determined from Fteley and Stearns' Experiments and as Computed by Various Formulas

Length of weir L	Height of weir P	Measured head H	Area of channel of approach divided by length of weir d	Velocity of approach V	Experimental discharge Q	By Basin's formula Q	By the author's formula Q	By Francis' formula Q	By Fteley and Stearns' formula Q
1	2	3	4	5	6	7	8	9	10
5.0	3.17	0.1	3.27	.04	.113	.128	.114	.105	.113
		0.2	3.37	.09	.308	.326	.314	.298	.302
		0.3	3.47	.16	.557	.579	.571	.548	.551
		0.4	3.57	.24	.857	.878	.877	.845	.848
		0.5	3.67	.33	1.193	1.217	1.218	1.182	1.188
		0.6	3.77	.42	1.570	1.604	1.598	1.560	1.560
		0.7	3.87	.52	1.990	2.004	2.013	1.966	1.968
		0.8	3.97	.62	2.450	2.450	2.461	2.408	2.417
19.0	6.55	0.5	7.05	.17	1.172	1.208	1.209	1.178	1.182
		0.6	7.15	.22	1.540	1.577	1.583	1.551	1.550
		0.8	7.35	.32	2.383	2.412	2.422	2.390	2.387
		1.0	7.55	.44	3.334	3.360	3.373	3.345	3.345
		1.2	7.75	.57	4.397	4.414	4.425	4.404	4.403
		1.4	7.95	.70	5.570	5.568	5.572	5.530	5.555
		1.6	8.15	.84	6.824	6.816	6.809	6.804	6.807

Table 105.—Showing Comparative Discrepancies between Fteley and Stearns' Experimental Values of Discharge over Suppressed Weirs and Discharges as Computed by Various Formulas

Name of formula	Length 5.0 Height 3.17		Length 19.0 Height 6.55		Total +	Total −	Sum of differences	Total + & −
	Discrepancy							
	+	−	+	−				
Basin	55	....	88	3	143	3	+140	146
Author's formula	48	....	117	5	165	5	+160	170
Francis'	....	41	27	36	27	77	−50	104
Fteley & Stearns	....	32	24	18	24	50	−26	74

In other words, formula (2) fits the experimental data in Table 102 better than any other formula of the type of equation (1). This refers to actual numerical discrepancies and not to percentages of error.

Discharges as computed by this formula are shown in column 11 of Table 102. The comparative discrepancy for each height of weir is shown in Fig. 89 and in Table 103. It will be seen that in general formula (2) agrees closer with the experiments than results by the author's formula (column 7) for the low weirs, while the author's formula agrees better for the higher weirs. In all cases the author's formula agrees closer with the experimental discharges for the lower heads. It is evident from a study of the data contained in Table 102, that if a formula of the type of equation (1) is to give results agreeing closely with the experiments for low heads, the exponent m must be approximately 1.47, since the term within the brackets is affected very little by the height of the weir and a comparatively large change must be made in the coefficient A to greatly effect the value of Q. In the last column of Table 103 it is shown that the total relative discrepancies of the author's formula and formula (2) are 249 and 207 respectively, a difference which is insignificant when the comparative simplicity of the two formulas is considered. It is also evident that the percentage of error in using the author's formula is less than for formula (2) since the discrepancies of the former are in all cases less for the lower heads. It therefore appears that the author's formula will give, within a very small margin, results agreeing as closely with the Bazin experiments as any formula of the type represented by equation (1).

Application of Formula to Contracted Weirs

Using the experiments of Francis and Fteley and Stearns as a basis the author has endeavored to adapt his formula to contracted weirs. In doing this the correction for end contraction has been taken as that determined by Francis, the effective length of the weir being

$$L = L' - 0.1NH$$

Undoubtedly some error is introduced in using this formula, and Francis states that it should not be used for weirs having a length less than three times the head.

In applying the author's formula to contracted weirs it should be borne in mind that the term d represents the cross-sectional area of the channel of approach per unit length of the weir, or

$$d = \frac{A}{L}$$

and for rectangular channels of approach

$$d = \frac{WG}{L}$$

In Table 106 the results obtained by the author's formula are compared with the experimental value of Francis and Fteley and Stearns. The results given cover practically the entire range of these experiments. The Francis experiments were performed on weirs 5.048 feet and 2.014 feet high and approximately 8 feet and 10 feet wide. The Fteley and Stearns experiments were conducted with a weir 3.56 feet high and from 2.3 to 4 feet wide.

The discharges over the Francis weirs were measured volumetrically. Fteley and Stearns determined the discharge over their contracted weirs by allowing the same quantity of water to pass over the same weir with contractions suppressed. The author recomputed the discharges in the Fteley and Stearns experiments by using the curve of discharge already referred to, page 388, from which the quantities in Table 104 for the suppressed weir 3.17 feet high were computed. The quantities taken from this curve were then corrected for velocity of approach to correspond to a weir 3.56 feet high. It is believed that this method gives results more in accord with the discharges measured volumetrically for the suppressed weir than the Fteley and Stearns method of using their formula to compute them.

Table 106 includes one experiment from each group of the Francis[1] experiments, the experiment chosen being the one in which the computed value of C came the nearest to the mean value of C for the group of experiments considered. Practically all of the Fteley and Stearns experiments on contracted weirs are included. Column 9 of this table gives the experimental or measured discharge over the weir. Columns 10, 11, and 12 show discharges as computed by the Francis formula, the Fteley and Stearns formula, and the author's formula respectively.

Fig. 91 shows graphically the discrepancies between experi-

[1] J. B. Francis: Lowell Hydraulic Experiments, pp. 122–125.

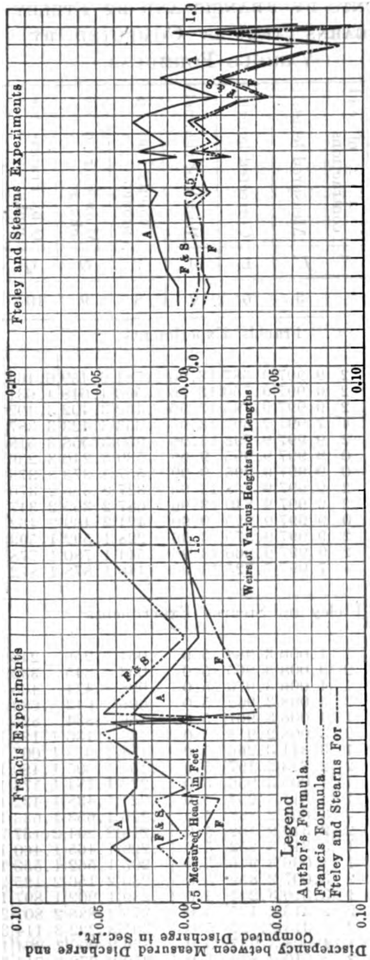


Fig. 91.—Discrepancies between experimental discharges over weirs with end contractions and discharges as computed by various formulas.

Table 106.—Showing Comparative Values of Discharge over Contracted Weirs as Determined by Experiments by Francis and by Fteley and Stearns and as Computed by Various Formulas

Height of weir	Measured head	Area of channel divided by length of weir	Number of end contractions	Measured length	Corrected length	Width of channel	Velocity of approach	Measured discharge	Q by Francis' formula	Q by Fteley and Stearns' formula	Q by the author's formula
P	H	d	N	L'	L	W	V	Q	Q	Q	Q
1	2	3	4	5	6	7	8	9	10	11	12
Francis' Experiments											
5.048	1.550	6.598	2	9.997	9.687	13.96	.781	6.459	6.469	6.519	6.460
5.048	1.242	6.290	2	9.997	9.750	13.96	.593	4.648	4.631	4.650	4.642
5.048	1.012	6.060	2	9.997	9.795	13.96	.452	3.402	3.402	3.407	3.425
5.048	1.010	6.058	4	7.997	7.593	13.96	.353	3.423	3.387	3.386	3.405
2.014	1.028	3.042	2	9.997	9.792	13.96	.950	3.558	3.519	3.605	3.588
5.048	0.977	6.025	0	9.997	9.995	9.99	.539	3.246	3.236	3.284	3.275
5.048	1.005	6.053	0	9.997	9.995	9.99	.557	3.373	3.378	3.395	3.416
5.048	0.796	5.844	2	9.997	9.838	13.96	.327	2.366	2.370	2.377	3.400
2.014	0.787	2.801	2	9.997	9.840	13.96	.687	2.365	2.347	2.384	3.400
5.048	0.815	5.863	0	9.997	9.995	9.99	.421	2.469	2.462	2.470	2.499
5.048	0.611	5.659	2	9.997	9.875	13.96	.228	1.592	1.593	1.599	1.624
2.014	0.655	2.669	2	9.997	9.866	13.96	.544	1.780	1.778	1.797	1.823
2.014	0.679	2.693	4	7.997	7.725	13.96	.446	1.878	1.872	1.880	1.911
Fteley and Stearns' Experiments											
3.56	0.176	3.736	1	4.006	3.988	5.0	.054	.256	.246	.252	.260
	.215	3 775	2	3.008	3.965	5.0	.053	.345	.332	.338	.349
	.269	3.829	1	4.006	3.979	5.0	.098	.474	.465	.467	.485
	.330	3.890	2	3.008	3.942	5.0	.096	.642	.632	.636	.657
	.394	3.954	1	4.006	3.967	5.0	.166	.834	.825	.832	.852
	.484	4.044	2	3.008	2.911	5.0	.162	1.136	1.123	1.125	1.152
	.450	4.010	1	3.311	3.266	5.0	.164	1.013	1.007	1.013	1.033
	.582	4.142	2	2.313	2.197	5.0	.158	1.505	1.480	1.480	1.510
	.498	4.058	1	4.006	3.956	5.0	.228	1.184	1.173	1.179	1.205
	.568	4.128	1	3.311	3.254	5.0	.224	1.438	1.432	1.430	1.461
	.621	4.181	2	3.007	2.883	5.0	.226	1.653	1.633	1.639	1.664
	.748	4.308	2	2.312	2.162	5.0	.219	2.204	2.157	2.158	2.187
	.576	4.136	1	3.310	3.252	5.0	.229	1.465	1.460	1.464	1.491
	.600	4.660	1	4.006	3.946	5.0	.295	1.562	1.553	1.559	1.588
	.740	4.300	2	3.007	2.859	5.0	.285	2.156	2.125	2.128	2.158
	.686	4.246	1	3.310	3.241	5.0	.289	1.902	1.897	1.900	1.931
	.890	4.450	2	2.313	2.135	5.0	.275	2.888	2.801	2.800	2.827
	.955	4.515	2	2.313	2.122	5.0	.301	3.222	3.114	3.115	3.136
	.706	4.266	1	4.008	3.937	5.0	.336	2.000	1.984	1.986	2.021
	.871	4.431	2	3.010	2.836	5.0	.352	2.778	2.715	2.717	2.745
	.806	4.366	1	3.311	3.230	5.0	.357	2.438	2.418	2.419	2.452
	.932	4.491	1	3.310	3.217	5.0	.430	3.030	3.005	3.012	3.036
	.943	4.503	1	4.004	3.910	5.0	.539	3.155	3.070	3.082	3.110

mental and computed discharges as determined from Table 106. Considerable irregularity exists in these discrepancies for each set of experiments as shown by the broken character of the lines. This may be due either to experimental error or to improperly applying the same correction for end contractions to all of the weirs.

Table 107, prepared from Fig. 91, shows comparative discrepancies between computed and experimental values of discharge. From the last column it will be seen that the author's formula agrees as closely with the experiments as the Francis or Fteley and Stearns formula. The next to the last column shows that the author's formula and the Fteley and Stearns formula give an average result slightly greater than the experimental values while the results by the Francis formula are less than those obtained from the experiments.

TABLE 107.—SHOWING COMPARATIVE DISCREPANCIES BETWEEN FRANCIS', AND FTELEY AND STEARNS' EXPERIMENTAL VALUES OF DISCHARGE OVER CONTRACTED WEIRS AND DISCHARGES AS COMPUTED BY VARIOUS FORMULAS

Name of formula	Francis' experiments		Fteley & Stearns experiments		Total +	Total −	Sum of differences	Total + & −
	Discrepancy							
	+	−	+	−				
Author's formula...	126	1	73	32	199	33	+166	232
Francis' formula....	7	91	......	140	7	231	−224	238
Fteley & Stearns....	178	1	......	113	178	114	+64	292

Comparison of Author's Submerged-weir Formula with Experiments.—Table 108 has been prepared to show comparative values of discharge as obtained from Bazin's experiments, the author's submerged-weir formula (formula (41), page 82) and the Bazin general formula (formula (32), page 79). The experimental discharges, given in column 7, were obtained by computing values of $\frac{m}{m'}$ by formulas (29) and (30), page 79, taking care to use each within the limits of its proper application and applying these values to Bazin's experimental dis-

charges over weirs of the same height with free overfall. These formulas were used only within the approximate range of the experimental data on which they were based. Since the curves of these formulas plot very precisely as a mean of the experimental points no appreciable error is introduced in using them instead of using the experimental results directly. It will be seen that the greatest divergence of results by the author's formula from Bazin's experimental results is approximately 2 per cent., while the total divergence is less than for the Bazin general formula (formula (32), page 79).

Table 109 shows a comparison of discharges over submerged weirs as determined from the Francis experiments of 1883, the Francis submerged-weir formula (formula (26), page 77), and the author's submerged-weir formula. The experimental values were obtained by determining the quantity of water that would flow over the same weir with free overfall by means of the Francis formula. Francis appears to have neglected the velocity of approach correction in computing his discharges over the weir with free overfall. The discharges corrected for velocity of approach are given in column 7. Francis experimented on two weirs having a combined length of 22.2 feet. A complete description of the apparatus used is not given and information as to the width of the channel below the weir is entirely lacking. From an examination of the sketch submitted with Francis' paper an assumption of a channel width below the weir of 1.6 times the combined length of weirs appeared conservative and this width was used in the computations. The height of the weir above the bottom of the lower channel was determined by scaling and taken as 7.3 feet. Owing to the lack of data regarding channel conditions below the weir some uncertainty exists as to the results obtained by the author's formula. Since, however, d_1 is sure to be a comparatively large quantity, considerable change in the area of the section of the lower channel will be necessary to greatly effect the computed discharges. It will be observed that the author's formula gives discharges from about 1 to 2 per cent. greater than the experimental values while the Francis formula gives results an equal amount less than the experiments. If a velocity-of-approach correction were applied to the Francis submerged-weir formula its agreement with the experiments would be closer but, in his discussion, Francis does not speak of the necessity for such a correction.

TABLE 108.—COMPARISON OF DISCHARGES OVER SUBMERG WEIRS AS DETERMINED BY BAZIN'S TWO PRECISE SUBMERGED-WEIR FORMULAS, WITH BAZIN'S GENERAL SUBMERGED-WEIR FORMULA AND THE AUTHOR'S SUBMERGED-WEIR FORMULA

Height of weir	Measured head	Area of channel of approach divided by length of weir	Depth of submergence	Difference in elevation of water surfaces	Area of channel below weir divided by length of weir	Experimental discharge by Bazin's formulas	Discharge by author's formula	Discharge by Bazin's general formula	$Q_7 - Q_8$	$Q_7 - Q_9$
P	H	d	D	Z	d_1	Q_7	Q_8	Q_9		
1	2	3	4	5	6	7	8	9	10	11
1.0	0.2	1.2	0.1	0.1	1.1	.28	.28	.28	.00	.0
	0.5	1.5	0.1	0.4	1.1	1.28	1.28	1.27	.00	+.0
		1.5	0.2	0.3	1.2	1.19	1.20	1.18	−.01	+.0
		1.5	0.4	0.1	1.4	.86	.86	.85	.00	+.0
	1.0	2.0	0.1	0.9	1.1	3.96	3.93	3.91	+.03	+.0
		2.0	0.3	0.7	1.3	3.79	3.80	3.75	−.01	+.0
		2.0	0.5	0.5	1.5	3.53	3.52	3.48	+.01	+.0
		2.0	0.7	0.3	1.7	3.07	3.05	3.04	+.02	+.0
		2.0	0.9	0.1	1.9	2.19	2.18	2.18	+.01	+.0
	1.5	2.5	0.3	1.2	1.3	7.60	7.56	7.50	+.04	+.1
		2.5	0.6	0.9	1.6	7.22	7.17	7.12	+.05	+.1
		2.5	1.0	0.5	2.0	6.28	6.14	6.34	+.14	−.0
		2.5	1.4	0.1	2.4	3.94	3.86	3.97	+.08	−.0
2.0	0.2	2.2	0.1	0.1	2.1	.28	.27	.28	+.01	.0
	0.5	2.5	0.1	0.4	2.1	1.21	1.21	1.21	.00	.0
		2.5	0.2	0.3	2.2	1.12	1.13	1.11	−.01	+.0
		2.5	0.4	0.1	2.4	.80	.79	.78	+.01	+.0
	1.0	3.0	0.1	0.9	2.1	3.62	3.60	3.61	+.02	+.0
		3.0	0.3	0.7	2.3	3.46	3.46	3.39	.00	+.0
		3.0	0.5	0.5	2.5	3.12	3.17	3.09	−.05	+.0
		3.0	0.7	0.3	2.7	2.72	2.72	2.65	.00	+.0
		3.0	0.9	0.1	2.9	1.91	1.92	1.87	−.01	+.0
	1.5	3.5	0.1	1.4	2.1	6.95	6.86	6.92	+.09	+.0
		3.5	0.3	1.2	2.3	6.77	6.77	6.70	.00	+.0
		3.5	0.6	0.9	2.6	6.38	6.38	6.28	.00	+.1
		3.5	1.0	0.5	3.0	5.44	5.43	5.35	+.01	+.0
3.0	0.2	3.2	0.1	0.1	3.1	.27	.26	.28	+.01	−.0
	0.5	3.5	0.1	0.4	3.1	1.16	1.18	1.20	−.02	−.0
		3.5	0.2	0.3	3.2	1.08	1.10	1.07	−.02	+.0
		3.5	0.4	0.1	3.4	.79	.75	.77	+.04	+.0
	1.0	4.0	0.1	0.9	3.1	3.49	3.49	3.51	.00	−.0
		4.0	0.3	0.7	3.3	3.25	3.32	3.27	−.07	−.0
		4.0	0.5	0.5	3.5	2.98	3.04	2.97	−.06	+.0
		4.0	0.7	0.3	3.7	2.59	2.59	2.53	.00	+.0
		4.0	0.9	0.1	3.9	1.82	1.80	1.78	+.02	+.0
	1.5	4.5	0.1	1.4	3.1	6.65	6.55	6.64	+.10	+.0
		4.5	0.3	1.2	3.3	6.43	6.44	6.40	−.01	+.0
		4.5	0.6	0.9	3.6	6.04	6.01	5.93	+.03	+.1
		4.5	1.0	0.5	4.0	5.11	5.11	5.00	.00	+.1
					Total + discrepancy				+.72	+1.3
					Total − discrepancy				−.27	−.1
					Total + & − discrepancy				.99	1.5

Table 109.—Comparison of Discharges over Submerged Weirs as Determined from Francis' Experiments of 1883, with the Francis Submerged-weir Formula and the Author's Submerged-weir Formula

Height of weir	Measured head	Area of upper channel divided by length of weir	Depth of submergence	$H-D$	Experimental discharge by Francis formula	Experimental discharge corrected for vel of approach	Discharge by Francis' submerged-weir formula	Discharge by author's submerged-weir formula	Q_7-Q_8	Q_7-Q_9
P	H	d	D	Z	Q_6	Q_7	Q_8	Q_9		
1	2	3	4	5	6	7	8	9	10	11
5.8	1.203	7.003	0.207	0.996	4.28	4.32	4.26	4.34	+.06	−.02
	1.227	7.027	0.309	0.918	4.28	4.32	4.29	4.36	+.03	−.04
	1.277	7.077	0.478	0.799	4.27	4.31	4.34	4.40	−.03	−.09
	1.391	7.191	0.860	0.531	4.26	4.30	4.17	4.28	+.13	+.02
	1.491	7.291	1.039	0.452	4.24	4.28	4.23	4.40	+.05	−.12
	1.720	7.520	0.466	1.254	7.17	7.26	7.03	7.25	+.23	+.01
	1.740	7.540	0.465	1.275	7.17	7.26	7.21	7.38	+.05	−.12
	1.743	7.543	0.483	1.260	7.16	7.25	7.20	7.38	+.05	−.13
	1.804	7.604	0.792	1.012	7.20	7.29	7.01	7.24	+.08	+.05
	1.917	7.717	0.996	0.921	7.17	7.26	7.34	7.58	−.08	−.32
	1.994	7.794	0.327	1.667	9.15	9.30	9.11	9.39	+.19	−.09
	2.034	7.834	0.528	1.506	9.14	9.29	9.14	9.43	+.15	−.14
	2.092	7.892	0.730	1.362	9.16	9.31	9.21	9.51	+.10	−.20
	2.090	7.890	0.732	1.358	9.17	9.32	9.19	9.49	+.13	−.17
	2.188	7.988	1.054	1.134	9.12	9.27	9.18	9.54	+.09	−.27
	2.190	7.990	1.071	1.119	9.12	9.27	9.15	9.52	+.12	−.25
	2.212	8.012	0.727	1.485	10.15	10.32	10.10	10.41	+.22	−.09
	2.319	8.119	1.111	1.208	10.10	10.27	10.04	10.49	+.23	−.22
	2.318	8.118	1.102	1.216	10.10	10.27	10.05	10.49	+.22	−.22
	1.037	6.837	0.263	0.774	3.31	3.33	3.33	3.38	.00	−.05
	1.091	6.891	0.448	0.643	3.31	3.32	3.37	3.41	−.05	−.09
	1.156	6.956	0.657	0.499	3.30	3.31	3.31	3.37	.00	−.06
	1.149	6.949	0.636	0.513	3.29	3.30	3.32	3.37	−.02	−.07
	1.328	7.128	1.015	0.313	3.28	3.29	3.19	3.36	+.10	−.07
					Total + discrepancy				+2.23	+0.08
					Total − discrepancy				−0.18	−2.83
					Total + & − discrepancy				2.41	2.91

A comparison of the author's submerged-weir formula with the experiments of Fteley and Stearns is given in Table 110. The experimental results are used directly without any attempt to balance experimental errors. The volume of water passing over the submerged weir in each set of experiments was obtained by allowing the same quantity of water to flow over the weir with free overfall, and computing the discharge.

The accuracy of the determination of the quantity of water flowing over the submerged weir therefore depends upon the method employed in computing the discharge over the weir with free overfall. Fteley and Stearns using their own experiments with those of Francis computed this discharge by means of the Francis formula. The author recomputed the discharges for the Fteley and Stearns experiments by means of the curve used in preparing column 6 of Table 104 for the weir 3.17 feet high, as already described (pages 388 and 392). Since Fteley and Stearns used this same weir for their submerged-weir experiments, placing obstructions in the channel to back the water up above the crest of the weir, it seems evident that greater accuracy may be obtained by taking directly the experimental values of discharges rather than to depend upon results computed by any formula.

Table 110, column 7 gives the experimental discharges as computed by Fteley and Stearns by means of the Francis formula. Column 8 gives the author's recomputed values as above described. Column 9 contains discharges as computed by the Fteley and Stearns submerged-weir formula (formula (27), page 77) with variable coefficient, and column 10 gives the discharges as computed by the author's submerged-weir formula. It will be seen from this table that the author's formula, in all cases, gives results greater than the experimental discharges. The discrepancies are within 3 per cent. for the smaller values of D, but increase as D becomes larger. It is probable that the agreement of the formula with these experiments would have been closer if D had been measured farther downstream, since, at a distance of 6 feet below the weir, a portion of the high velocity possessed by the water passing over the weir still remained to be converted into static head. This condition it appears would be more noticeable for the larger values of D, for in this case the water would leave the weir in a more nearly horizontal direction causing a smaller loss of head due to change of direction and resulting turbulence.

TABLE 110.—COMPARATIVE VALUES OF DISCHARGE OVER SUBMERGED WEIRS AS DETERMINED FROM EXPERIMENTS BY FTELEY AND STEARNS AND AS COMPUTED BY THE FTELEY AND STEARNS' FORMULA AND BY THE AUTHOR'S SUBMERGED-WEIR FORMULA

Height of weir P (1)	Measured head H (2)	Area of upper channel divided by length of weir d (3)	Depth of submergence D (4)	$H-D$ Z (5)	Area of lower channel divided by length of weir d_1 (6)	Experimental discharge by Francis' formula Q_7 (7)	Experimental discharge direct from Fteley & Stearns' experiments Q_8 (8)	Q by F. & S. formula with variable coefficient Q_9 (9)	Q by author's submerged-weir formula Q_{10} (10)	Q_8-Q_9 (11)	Q_8-Q_{10} (12)
3.17	.578	3.748	.010	.568	5.217	1.46	1.49	1.46	1.52	.03	−.03
	.396	3.566	.016	.380	5.228	.83	.85	.83	.86	.02	−.01
	.662	3.832	.033	.629	5.257	1.81	1.84	1.81	1.86	.03	−.02
	.574	3.744	.046	.528	5.280	1.47	1.49	1.46	1.49	.03	.00
	.508	3.678	.073	.435	5.327	1.20	1.22	1.20	1.22	.02	.00
	.592	3.769	.112	.480	5.395	1.47	1.49	1.48	1.52	.01	−.02
	.416	3.586	.118	.298	5.405	.83	.85	.84	.87	.01	−.02
	.325	3.495	.096	.229	5.367	.56	.57	.57	.59	.00	−.02
	.610	3.780	.186	.424	5.524	1.47	1.49	1.47	1.53	.02	−.04
	.716	3.886	.266	.450	5.663	1.81	1.84	1.81	1.90	.03	−.06
	.546	3.716	.209	.337	5.565	1.20	1.22	1.20	1.25	.02	−.03
	.633	3.803	.261	.372	5.654	1.46	1.49	1.48	1.54	.01	−.05
	.450	3.620	.219	.231	5.583	.83	.85	.84	.88	.01	−.03
	.486	3.656	.308	.178	5.736	.83	.85	.83	.88	.02	−.03
	.812	3.982	.516	.296	6.098	1.81	1.84	1.80	1.93	.04	−.09
	.742	3.912	.519	.223	6.103	1.46	1.49	1.47	1.57	.02	−.08
	.545	3.715	.419	.126	5.929	.83	.85	.84	.89	.01	−.04
	.428	3.598	.337	.091	5.786	.56	.57	.56	.60	.01	−.03
	.719	3.889	.573	.146	6.197	1.20	1.22	1.20	1.30	.02	−.08
	.625	3.795	.589	.036	6.223	.56	.57	.56	.66	.01	−.09
	.815	3.985	.795	.020	6.583	.56	.57	.57	.77	.00	−.20
					Total + discrepancy					.37	.00
					Total − discrepancy					.00	−.98
					Total + & − discrepancy					.37	.98

Since Francis measured the head of submergence "just below the weir" in his experiments of 1848 the author's formula cannot be applied to them. Table 111 shows a comparison of the results of these experiments with formula (42), page 83. The discrepancy in each case is less than 3 per cent. *D* was probably measured near the trough of the standing wave and the rather close agreement between the computed and experimental values is some evidence to substantiate the author's opinion that formula (42) will give approximate discharges over submerged weirs if the head of submergence is measured in the trough of the standing wave.

It is impossible to make a thoroughly consistent comparison of the four sets of experiments described above with the author's formula because of the different points chosen by the experimenters in measuring the head of submergence. It seems fair to conclude, however, from a study of the results given in Tables 108, 109 and 110 that if the head of submergence is measured at a point corresponding to that chosen by Bazin (36 feet below the weir), the author's submerged-weir formula should give results correct within from 1 to 3 per cent.

TABLE 111.—COMPARATIVE DISCHARGES OVER SUBMERGED WEIR AS DETERMINED FROM FRANCIS' EXPERIMENTS OF 1848 AND THE AUTHOR'S FORMULA

Height of weir	Measured head	Area of upper channel divided by length of weir	Depth of submergence	$H-D$	Experimental discharge by Francis' formula	Discharge by F. & S. formula with variable coef.	Discharge by formula (42)		
P	H	d	D	Z	Q_6	Q_7	Q_8	Q_6-Q_7	Q_6-Q_8
1	2	3	4	5	6	7	8	9	10
6.5	.853	7.353	.020	.833	2.62	2.63	2.65	−.01	−.03
	.848	7.348	.065	.783	2.62	2.63	2.55	−.01	+.07
	.852	7.352	.085	.767	2.62	2.64	2.58	−.02	+.04
	.857	7.357	.105	.752	2.62	2.64	2.58	−.02	+.04
	.882	7.382	.220	.662	2.62	2.62	2.57	.00	+.05
	.970	7.470	.490	.480	2.62	2.62	2.55	.00	+.07
				Total + discrepancy				.00	+.27
				Total − discrepancy				−.06	−.03
				Total + & − discrepancy				.06	.30

Causes of Inconsistencies in Weir Experiments

A careful scrutiny of the foregoing experiments reveals many apparent inconsistencies in the results of the different investigators. It will be noted, however, that in every case each set of experiments is consistent in itself within the limits of experimental error. The conclusion must be that such inconsistencies are due to different conditions under which the experiments have been performed and failure to consider certain fundamental underlying principles.

Probably the most noticeable incongruity exists in the experimental results of Bazin and Fteley and Stearns. Each set of experiments is consistent in itself and apparently each was performed with great care and under equally favorable circumstances. It would therefore appear that some difference in conditions, which enters into the relation between head and discharge, existed which has not hitherto been considered in weir investigations, and for the more precise use of weirs, corrective factors to allow for such conditions should be included in weir formulas.

Explanation of the reasons for these conflicting experimental data has hardly passed the stage of conjecture. Apparently the inconsistencies in the Bazin and Fteley and Stearns experiments are not due to the different methods employed in measuring heads nor differences in the shape or degree of sharpness of weir crests. Barr, experimenting with V-notch weirs, (page 87) found that increasing the roughness of the upstream face of a weir, by reducing the vertical component of the velocity of approach and so reducing crest contraction, increased the discharge. A similar relation between degree of roughness of upstream face and discharge may exist for rectangular weirs. It is also probable that the discharge over weirs increases slightly with the temperature of the water due to a diminution of the coefficient of viscosity.

It is important that future experimenters should give complete data relative to temperature of the water and degree of roughness of the upstream face of the weir. All dimensions and a detailed description of the apparatus used in experiments should also be given. In general it may be stated that before materially greater precision in the measurement of flow over weirs may be expected, the fundamental laws affecting such flow must be more thoroughly investigated.

APPENDIX B

Comparison of Kutter, Manning and Bazin Formulas with Scobey's Experiments

Table 112, as given in the following pages, is a reproduction of experiments and computations prepared by F. C. Scobey, and published in *Bulletin* 194 of the United States Department of Agriculture with the addition of the last three columns which give coefficients for Manning's and Bazin's formulas. A comparison of Kutter's n and Manning's n, as given respectively in columns 15 and 16, will be found especially enlightening. Column 18 gives values of Bazin's m for each experiment, exeept where m is negative.

As stated on page 198 the author has found that the Manning formula gives practically the same results as the Kutter formula, within the ordinary range of conditions encountered in practice, when the same value of n is used with each formula. Scobey's experiments show this to be true to a remarkable degree.

Table 112 may be used to advantage in connection with Table 73, page 191, or Table 74, page 193, in selecting coefficients for either the Kutter, Manning, or Bazin formulas. In designing canals, too much care and study can not be exercised in selecting the coefficient which will most accurately apply to the given conditions. It is still very doubtful whether any one of the above formulas conforms closely to the laws of flow in open channels and it is therefore desirable, in each case, to select a coefficient from experiments on a channel resembling as closely as may be the channel to be designed. This refers to channel dimensions and alignment as well as to the degree of roughness of the channel. Since the following table gives quite full data in these regards it should furnish valuable assistance in the intelligent selection of coefficients.

TABLE 112.—ELEMENTS OF EXPERIMENTS FOR THE DETERMINATION OF RETARDATION FACTORS IN THE CHEZY, KUTTER, MANNING AND BAZIN FORMULAS*

1 Reference number	2 Class (accuracy)	3 Name and description of channel	4 Length of reach tested, ft.	5 Approximate surface width, ft.	6 Approximate maximum depth, ft.	7 Average depth, ft.	8 Area of water section, sq. ft. a	9 Mean velocity per second, ft. v	10 Discharge per second, cu. ft. Q	11 Wetted perimeter, ft. p	12 Hydraulic mean radius, ft. r	13 Hydraulic grade s	Coefficients of retardation: 14 Chezy c	15 Kutter n	16 Manning n	17 Manning $\frac{K = 1.486}{n}$	18 Bazin, m
		Concrete-lined															
1	C	New York Canal	602.0	59.0	6.6	5.6	332.9	5.48	1,824.00	63.60	5.23	.0001611	188.7	.0101	.0105	142.2	
2a		Main Canal, Boise project	2,400.0	49.1	2.97	....	123.5	3.81	469.70	50.30	2.45	.0003333	133.4	.0130	.0128	116.4	.283
3a		Main Canal, Boise project	1,000.0	53.7	4.75	....	219.5	4.68	1,027.37	56.50	3.88	.0003875	120.6	.0154	.0156	95.5	.611
4a		Sulphur Creek wasteway	1,300.0	....	2.3	....	11.75	20.62	242.00	9.03	1.30	.0144	150.5	.0108	.0104	143.8	.057
5a		Sulphur Creek wasteway, curve	900.0	....	2.4	....	12.67	19.13	242.00	9.32	1.36	.0206	114.1	.0140	.0138	107.9	.444
6a		Los Angeles conduit, curve	700.0	....	....	....	5.16	2.81	14.51	6.22	.83	.00051	136.7	.0108	.0106	140.5	.136
7a		Los Angeles conduit, curve	700.0	....	....	....	5.00	2.71	13.55	6.12	.82	.00051	132.6	.0111	.0108	137.9	.173
8a		Tunnel 23, San Gabriel Plant	318.0	4.5	3.5	....	15.73	4.74	74.64	11.50	1.37	.00082	141.6	.0113	.0111	134.2	.129
9a		Dry Creek flume, troweled cement	514.5	7.9	1.30	....	9.76	15.78	154.00	10.35	.94	.01459	134.5	.0115	.0110	135.4	.165
10a		Tunnel 15, San Gabriel Plant	446.0	4.5	3.13	....	14.08	5.01	70.60	10.71	1.31	.00126	123.3	.0128	.0127	117.3	.321
11	A	Ridenbaugh, very smooth	1,699.0	22.8	4.30	3.10	70.73	4.15	293.62	25.20	2.81	.0002371	161.5	.0110	.0109	136.7	
12		Ridenbaugh, tangent	901.0	22.0	3.80	2.76	60.60	3.65	221.20	23.90	2.54	.0002508	144.8	.0121	.0121	123.1	.144
13		Ridenbaugh, tangent and curves	1,819.0	22.0	3.80	2.76	60.50	3.65	221.20	23.90	2.54	.0002837	136.1	.0129	.0128	116.4	.256
14		Ridenbaugh, tangent and curves	1,020.6	23.6	4.55	3.24	76.59	4.14	316.70	26.34	2.91	.000283	.....	.0124			
15a		Ridenbaugh, curves	2,400.0	15.5	1.65	1.36	20.59	2.45	50.49	15.9	1.30	.000329	118.1	.0132	.0132	112.8	.382
16a		Lizard chute No. 1, smooth	180.0	3.1	.36	....	.....	15.05	16.42	.....	.29	.08244	97.4	.0124	.0124	120.2	.335
17a		Lizard chute No. 1, same reach	180.0	3.0	.11	....	.....	6.18	2.04	.....	.10	.08244	67.2	.0130	.0150	99.3	.432
18a		Long Pond chute, smooth	600.0	4.4	1.53	....	6.24	19.70	122.94	7.24	.86	.02971	122.4	.0123	.0118	126.3	.270
19a		Long Pond chute, same reach	600.0	4.4	.71	....	2.78	12.87	35.79	5.68	.49	.02978	106.6	.0125	.0124	120.2	.336
20a		Umatilla project, smooth	932.0	....	....	....	2.76	2.06	5.70	4.76	.58	.0007	102.0	.0130	.0134	111.2	.411
21a		Umatilla project, tangent	640.0	....	4.00	....	28.95	7.10	205.00	13.50	2.13	.0014	129.0	.0132	.0131	113.7	.321
22a		Umatilla project, wavy	1,075.0	....	2.98	....	28.71	7.15	205.00	13.50	2.12	.00177	119.0	.0142	.0142	104.9	.467
23a		Umatilla project, curve	220.0	....	4.05	....	29.40	6.94	205.00	13.50	2.15	.00273	90.0	.0189	.0189	78.8	1.10
24a		Arena chute, smooth, straight	100.0	6.1	.24	....	.....	16.38	23.26	.....	.22	.02056	77.2	.0139	.0149	100.0	.489
25	B	North Side Twin Falls Main	1,900.0	....	....	....	321.10	8.21	2,637.00	59.20	5.43	.0006389	139.4	.0138	.0143	104.2	.303

26		Davis and Weber, medium smooth	552.0	27.8	2.89	2.49	69.29	3.82	364.50	29.66	2.34	.000413	125.7	.014	.0136	109.5	.383
27	*B*	Davis and Weber, medium smooth	....	.....	.....	1.75	34.20	3.89	133.30	23.95	1.50	.000626	110.0	.0144	.0145	102.7	.529
28		Davis and Weber, medium smooth	468.5	22.8	1.77	1.59	36.18	3.34	120.90	24.07	1.50	.000619	109.0	.0146	.0147	101.4	.554
29	*A*	Davis and Weber, medium smooth	1,000.0	23.0	2.60	2.34	53.80	3.94	212.00	26.00	2.07	.000629	109.7	.0154	.0154	96.7	.634
30		King Hill, rough, curves..........	925.0	16.5	....	1.62	21.40	2.55	54.64	17.16	1.25	.0004497	107.5	.0143	.0144	103.4	.521
31	*A*	Hamilton Mill Flume, new.......	3,000.0	7.0	4.11	4.11	27.90	3.86	107.60	14.38	1.94	.00062	111.4	.0149	.0150	99.3	.570
32*a*		South Canal....................	730.0	14.7	1.77	1.71	23.66	4.71	111.30	16.82	1.41	.00151	102.1	.0155	.0155	96.1	.643
33*a*		South Canal....................	210.0	10.4	.57	.56	5.78	15.52	89.80	11.28	.51	.07180	80.8	.0158	.0164	90.8	.679
34*a*		South Canal....................	142.0	13.3	.45	.40	5.28	11.32	59.68	13.92	.38	.07230	68.4	.0171	.0184	80.9	.806
35	*A*	Sanderfer, smooth tangent........	743.3	3.5	1.80	1.43	5.00	3.74	18.71	5.94	.84	.002375	92.0	.0155	.0155	94.9	.653
36*a*		Santa Ana, sand.................	1,000.0	....	....	....	10.21	2.62	26.79	12.50	.82	.00106	89.2	.0157	.0161	92.6	.701
37	*A*	Lateral 12, Orland project........	206.0	5.4	.78	.57	3.06	1.86	5.71	5.67	.54	.00099	80.2	.0160	.0167	89.2	.718
38	*A*	Lateral 12, Orland project........	755.8	5.4	.80	.62	3.33	1.71	5.71	5.74	.58	.001184	65.2	.0192	.0208	71.6	1.08
39*a*		Colton, tangent, moss............	1,000.0	....	....	....	6.75	2.27	15.34	6.88	.98	.0007	87.7	.0167	.0170	87.6	.792
40	*A*	South Cottonwood Ward, sand...	350.0	2.6	.90	.80	2.07	1.38	2.86	3.98	.52	.000694	72.6	.0171	.0185	80.6	.843
41	*A*	Modesto main, rocks............	755.6	21.0	1.55	1.52	32.06	3.58	114.80	23.22	1.38	.001157	89.7	.0174	.0175	85.1	.897
42	*A*	Santa Ana main, deposit, sand...	1,082.8	11.5	1.58	1.41	16.18	1.67	27.16	13.25	1.22	.0003208	84.6	.0176	.0182	81.8	.951
43	*A*	Los Nietos, deposit, sand........	600.5	4.4	2.15	1.52	6.69	2.89	19.36	6.81	.98	.001444	76.8	.0188	.0194	76.8	1.04
44	*A*	Arroyo Ditch, tangent, moss......	1,000.0	4.1	1.90	1.60	6.56	2.83	18.54	6.89	.95	.001449	76.2	.0188	.0194	76.8	1.04
45	*A*	North Canal, rough, tangent.....	240.0	12.9	2.78	2.58	33.38	2.94	98.30	17.20	1.94	.000525	92.5	.0177	.0180	82.7	.973
46	*A*	North Canal, tangent and curve...	1,013.0	12.9	2.78	2.58	32.52	3.02	98.30	17.10	1.90	.000639	86.9	.0187	.0191	78.0	1.12
47	*A*	North Canal, tangent...........	240.0	12.7	2.22	2.07	26.26	2.85	74.86	16.15	1.63	.000629	90.8	.0176	.0178	83.7	.942
48	*A*	North Canal, tangent and curve..	1,013.0	12.7	2.22	2.05	26.05	2.87	74.86	16.10	1.62	.000729	83.5	.0190	.0193	77.2	1.13
49	*A*	North Canal, tangent...........	240.0	12.4	1.10	.99	12.25	2.10	25.74	13.87	.88	.000950	72.5	.0192	.0202	73.7	1.11
50	*A*	North Canal, tangent and curve .	1,013.0	12.4	1.10	1.02	12.61	2.04	25.74	13.90	.91	.001021	67.1	.0206	.0209	71.3	1.29
51	*A*	Main, Orland project............	301.0	21.0	2.20	1.77	37.09	2.27	84.32	22.75	1.63	.000574	74.3	.0211	.0219	68.0	1.43
52*a*		Upper, Riverside, two curves.....	600.0	....	....	....	6.96	1.22	8.50	9.89	.70	.00063	58.0	.0218	.0242	61.6	1.44
53	*B*	Small ditch, cement wash	575.4	2.7	1.70	1.04	2.82	1.07	3.02	4.52	.62	.0005839	56.1	.0220	.0245	60.8	1.43
54	*A*	Lower, Riverside, rough, broken..	699.0	11.0	1.30	1.14	12.57	1.88	23.64	12.30	1.02	.000851	63.8	.0221	.0235	63.4	1.48
55	*A*	Upper, Riverside, sandy bottom..	329.6	12.9	2.20	2.07	26.68	1.79	47.83	16.64	1.60	.000482	64.4	.0231	.0250	59.6	1.84
56*a*		Upper, Riverside, sand, grass.....	800.0	....	....	....	30.92	1.96	60.52	20.74	1.49	.00092	52.9	.0284	.0302	49.3	2.41
		Wooden Flumes	....														
57	*A*	Reno, surfaced, battened.........	800.0	9.6	....	5.61	56.11	4.49	251.80	24.60	2.28	.0003108	169.0	.0103	.0101	147.5	
58	*A*	Bitter Root Valley Irrigation Co.	500.0	17.7	....	2.51	44.05	3.23	142.10	22.70	1.94	.00024	150.0	.0112	.0111	134.2	.071
59	*A*	King Hill, smooth..............	1,119.0	6.5	....	2.28	15.02	5.79	86.99	10.85	1.35	.001288	139.2	.0115	.0113	131.8	.153
60*a*		Orchard Mesa Power, surfaced.	....	12.0	....	2.28	27.54	5.08	139.50	16.60	1.66	.000713	149.7	.0112	.0108	137.9	.064

* Columns 1–15 inclusive, from *Bulletin* No. 194, U. S. Department Agriculture. Columns 16, 17, 18 computed and added by M. J. Orbeck, C. N. Ward, W. O' B. Henderson.

TABLE 112 (*Continued*)

1 Ref. no.	2 Class	3 Name and description	4 L	5 App. width	6 Max. depth	7 Av. depth	8 a	9 v	10 Q	11 p	12 r	13 s	14 c	15 K's n	16 M's n	17 M's K	18 m
61a		**Orchard Mesa Power, Surfaced**	....	12.0	....	1.40	16.77	3.80	63.30	15.10	1.11	.000710	136.2	.0114	.0111	134.2	.166
62a		Orchard Mesa Power, Surfaced	....	12.0	....	2.94	35.21	5.96	209.30	17.97	1.96	.000965	138.9	.0123	.0120	124.2	.189
63a		Orchard Mesa Power, Surfaced	....	12.0	....	3.29	39.45	5.81	228.80	18.60	2.12	.000858	137.6	.0126	.0123	121.2	.211
64	A	Central Oregon Irrigation Co., surfaced	1,100.0	16.0	....	2.74	43.82	9.12	399.77	23.10	1.90	.00210	144.7	.0117	.0115	129.5	.123
65	A	Alkali Creek, waterworn, slime	834.0	10.0	....	2.08	20.80	7.80	160.79	14.15	1.47	.00213	139.0	.0118	.0114	130.7	.162
66	A	Alkali Creek, waterworn, slime	834.0	10.0	....	2.12	21.20	7.30	153.40	14.24	1.49	.00213	129.0	.0126	.0124	120.2	.271
67	A	Alkali Creek, waterworn, slime	834.0	10.0	....	2.61	26.10	7.93	206.88	15.22	1.72	.00213	131.0	.0127	.0125	119.2	.266
68	A	Alkali Creek, waterworn, slime	834.0	10.0	....	1.63	16.30	5.45	88.74	13.26	1.23	.00213	106.0	.0149	.0145	102.7	.540
69a		Fargo drop, plank, tar-coated	250.0	6.1	.25	....	......	14.31	21.82	......	.23	.01054	91.7	.0122	.0127	117.3	.345
70	A	Bitter Root Valley Irrigation Co.	700.0	15.8	....	2.53	40.00	2.32	92.80	20.86	1.92	.00016	132.5	.0125	.0126	118.2	.263
71	A	Bitter Root Valley Irrigation Co.	1,000.0	15.7	....	2.33	36.70	2.60	95.50	20.40	1.80	.000225	129.5	.0127	.0127	117.3	.291
72	B	Hedge, new, surfaced	150.0	9.6	....	2.32	31.90	2.08	66.50	16.30	1.96	.000133	129.0	.0129	.0129	115.4	.311
73		Bitter Root Valley Irrigation Co.	1,000.0	17.7	....	3.00	53.10	2.67	142.10	23.70	2.24	.00020	126.0	.0135	.0136	109.6	.376
74	A	Billings Land and Irrigation Co., Lateral No. 4	606.0	2.0	....	.66	1.32	1.64	2.16	3.32	.40	.000868	88.3	.0138	.0145	102.7	1.28
75	A	Telluride flume, surfaced	400.0	5.9	....	4.37	25.65	6.21	159.34	14.60	1.66	.00169	117.1	.0141	.0139	107.2	.446
76a	B	Bear River, surfaced	125.0	....	....	....	11.78	5.46	64.34	13.62	.87	.0032	103.4	.0142	.0141	105.6	.480
77	A	Arnold, curve and tangent	616.0	11.9	....	1.45	17.27	3.71	64.02	17.45	.99	.001044	115.5	.0131	.0129	115.5	.363
78	A	Arnold, curves and tangents	2,200.0	11.9	....	1.57	18.63	3.44	64.02	17.65	1.06	.001048	103.5	.0145	.0145	102.7	.538
79	A	Arnold, curve	437.0	11.9	....	1.61	19.15	3.34	64.02	17.70	1.08	.001035	100.2	.0150	.0150	99.4	.594
80	A	Arnold, tangent	1,147.0	11.9	....	1.61	19.19	3.34	64.02	17.75	1.08	.001054	98.7	.0152	.0153	97.4	.620
81a		Oxford, floor transverse	1,712.0	9.7	1.42	1.07	10.41	1.54	16.01	7.23	.93	.000274	96.4	.0150	.0153	97.4	.612
82	A	Hedge, old, surfaced	750.0	7.8	....	2.85	22.10	3.13	69.07	13.47	1.64	.00053	106.0	.0153	.0153	97.4	.624
83	A	Hedge, old, surfaced	1,000.0	7.6	....	2.79	21.30	3.06	65.20	13.02	1.62	.00053	104.5	.0155	.0155	96.2	.647
84	B	Swalley, tangent and curve	159.0	10.0	....	1.23	12.34	4.08	50.31	13.66	.90	.001934	97.5	.0149	.0150	99.4	.584
85	A	Swalley, tangent and curves	598.0	10.0	....	1.26	12.61	3.99	50.31	13.63	.93	.002019	92.9	.0156	.0158	94.3	.682
86	B	Swalley, tangent	195.0	10.0	....	1.39	13.92	3.61	50.31	13.90	1.00	.001479	93.8	.0157	.0159	93.8	.680
87	B	Swalley, tangent and curve	244.0	10.0	....	1.16	11.56	4.35	50.31	13.30	.87	.002145	99.3	.0157	.0146	102.0	.548
88	B	Golden Rock Lower, rough	163.2	5.9	....	.91	5.38	1.30	6.97	8.20	.66	.0008615	84.1	.0159	.0165	90.8	.710

89	*B*	Modesto main, asphalted	470.0	13.7	....	2.91	39.91	1.08	43.05	20.55	1.94	.0000568	97.4	.0163	.0171	87.0	.861
90	*B*	Lateral, Salt Lake City and Jordan	400.0	4.5	....	.80	3.60	6.11	21.96	6.12	.59	.01069	76.9	.0167	.0177	84.1	.806
91	*A*	Wheeler, battens, worn, sand	1,014.4	6.5	....	1.87	12.11	1.60	19.35	11.60	1.04	.0003249	86.9	.0167	.0173	86.3	.830
92a		Elm farm, projecting calking	....	....	....	....	1.49	.65	.97	4.51	.33	.00038	57.6	.0184	.0214	69.5	1.00
93		Roller flume, slimed	500.0	13.0	....	2.94	55.30	1.22	67.25	23.00	2.30	.000084	87.5	.0191	.0196	75.9	1.22
94	*A*	Lower, Riverside, asphalted	746.3	7.4	....	.88	6.60	3.58	23.64	9.21	.72	.003915	67.6	.0196	.0208	71.5	1.13
95a	*B*	Bear River, Rocks on bottom	150.0	....	....	....	66.60	2.97	197.50	23.32	2.86	.0004	87.7	.0201	.0203	73.3	1.35
96	*A*	Fullerton, sand and moss	672.1	9.8	....	1.04	10.09	1.56	15.72	11.75	.86	.0006299	67.0	.0202	.0217	68.7	1.25
97a	*B*	Bear River, gravel	100.0	....	....	....	84.05	2.46	207.00	28.60	2.94	.00031	81.8	.0217	.0219	68.1	1.59
		Metal Flumes															
98a	*B*	Minnesota, smooth, tangent	200.0	2.8	.66	....	1.17	6.01	7.04	3.13	.37	.0052	136.2	.0099	.0092	161.2	.098
99a		Garland, smooth, tangent	650.0	5.7	1.11	....	3.66	5.34	19.59	6.00	.61	.0023	142.3	.0101	.0096	154.5	.086
100a		Boise project, smooth	....	2.1	.68	....	....	1.66	1.71	....	.38	.0005	119.7	.0106	.0105	141.2	.192
101a		Boise project, smooth, No. 80	....	3.1	.75	....	....	2.37	3.36	....	.41	.00113	109.9	.0117	.0116	127.9	.275
102a		Moro Canal, smooth, No. 108	....	3.5	.70	....	....	2.55	4.02	....	.41	.00117	116.6	.0112	.0110	135.7	.224
103a		Yarnell lateral, smooth, No. 172	....	2.6	.55	....	....	2.88	2.57	....	.32	.00175	121.5	.0122	.0101	147.2	.171
104a		Garland, smooth, tangent	325.0	5.8	1.12	....	4.25	4.40	19.59	6.44	.69	.0022	112.5	.0126	.0124	119.7	.332
105a		Partridge lateral, projecting bands	....	2.0	.57	....	....	1.82	1.39	....	.32	.00120	93.6	.0127	.0131	113.6	.388
106a		Golden Gulch, projecting bands	....	4.5	1.50	....	....	1.43	6.81	....	.84	.00020	109.9	.0129	.0132	113.2	.395
107a		Ten-mile feeder, projecting bands	....	5.2	1.65	....	....	1.38	8.08	....	.91	.000175	109.6	.013	.0134	111.3	.421
108a		South Ridge, projecting bands	....	2.2	.50	....	....	1.68	1.34	....	.31	.00130	83.4	.0139	.0146	101.7	.498
109a		King lateral, projecting bands	300.5	5.1	2.00	....	7.32	5.35	39.19	6.82	1.07	.00386	83.1	.0179	.0181	82.2	.936
110a		King lateral, projecting bands	189.0	5.0	1.68	....	5.77	5.77	33.30	6.30	.92	.00537	82.3	.0177	.0178	83.4	.873
111a		King lateral, projecting bands	635.0	4.2	1.57	....	4.65	5.10	23.72	5.53	.84	.00411	86.6	.0166	.0167	89.1	.754
112a		Stuart, curve, corrugated iron	1,745.0	6.0	1.77	....	7.67	1.92	14.70	7.35	1.04	.000892	62.8	.0222	.0239	62.2	1.54
		Masonry-lined															
113	*A*	Jacobs, rubble sides	225.0	4.2	1.50	1.40	5.90	3.82	19.44	6.90	.86	.001367	111.5	.0130	.0130	114.3	.381
114a		Cottonwood flume, rubble	....	5.7	1.30	....	....	6.17	29.42	....	.86	.005575	89.3	.0163	.0163	91.6	.707
115	*A*	Jacobs, unchinked sides	280.0	7.4	1.95	1.77	13.06	1.49	19.44	10.62	1.23	.000471	61.9	.0235	.0249	59.8	1.71
116	*A*	Jacobs, plastered sides	280.5	5.1	1.77	1.70	8.62	2.26	19.44	8.21	1.05	.001597	55.5	.0250	.0271	55.1	1.89
117	*B*	Orr, mortar laid	213.6	11.5	2.70	2.26	26.02	1.76	45.80	14.65	1.78	.000636	52.4	.0298	.0314	47.5	2.68
		Earth Channels															
118a		Interstate, cemented clay	....	....	....	....	207.50	4.75	830.00	52.10	3.88	.00017	185.0	.0120	.0101	147.4	
119	*B*	Farmer's, cemented clay	1,000.0	51.0	3.70	2.53	129.06	2.56	330.00	53.80	2.40	.000154	133.0	.0130	.0130	114.6	.288
120	*A*	Farmer's, cemented clay	1,200.0	51.0	3.90	2.74	139.81	2.22	310.84	53.30	2.62	.00017	105.2	.0164	.0167	89.3	.806
121a		Bear River, sediment	....	22.9	3.95	2.70	62.30	3.62	225.55	25.00	2.49	.00031	130.2	.0134	.0134	111.5	.333
122a		Bear River, City, sediment	....	11.4	1.22	.90	10.24	1.04	10.68	11.85	.86	.00012	102.2	.0135	.0142	104.8	.502

TABLE 112 (*Continued*)

1 Ref. no.	2 Class	3 Name and description	4 L	5 App. width	6 Max. depth	7 Av. depth	8 a	9 v	10 Q	11 p	12 r	13 s	14 c	15 K's n	16 M's n	17 M's K	18 m
123a	B	Bear River, Corinne Branch, silt..	100.0	23.9	2.80	1.94	4.44	2.36	109.56	24.98	1.86	.00027	105.8	.0155	.0156	90.5	.670
124a		Bear River, Corinne Branch, loam	......	18.9	2.24	1.67	31.66	2.02	64.02	19.78	1.60	.000273	96.8	.0164	.0167	89.5	.795
125a		Fort Lyons, silt, very smooth....	2,600.0	68.0	1.20	1.13	75.60	1.86	140.55	66.80	1.13	.00038	89.5	.0165	.0170	87.7	.810
126	B	Maricopa, hard bed............	900.0	29.0	3.00	2.31	66.93	1.28	85.51	31.50	2.20	.0000804	99.3	.0166	.0172	86.9	.871
127	A	Winter Creek, compact clay......	800.0	13.5	1.70	1.02	13.71	.93	12.77	13.90	.99	.0001341	80.9	.0170	.0184	81.0	.943
128a		Empire intake, sand, gravel......	400.0	48.0	4.00	2.83	135.90	2.94	372.10	41.70	2.84	.00025	103.0	.0170	.0173	86.3	.895
129a		Empire intake, firm gravel.......	400.0	....	....	....	71.20	2.46	175.50	41.43	1.73	.00050	83.6	.0194	.0196	76.2	1.16
130	A	Billings Land and Irrigation Co., slick loam..................	1,000.0	24.0	3.80	2.85	68.40	2.45	167.56	26.30	2.60	.000230	100.0	.0174	.0175	85.1	.929
131a		Jarbeau Power, clay loam........	900.0	13.6	1.40	1.21	16.43	1.96	32.27	14.75	1.11	.00049	83.8	.0176	.0181	82.4	.929
132	B	Cove, sandy loam, grass..........	600.0	4.5	.75	.53	2.37	1.14	2.70	5.00	.47	.000617	66.6	.0180	.0197	75.6	.938
133	B	Cove, sandy loam, grass..........	400.0	5.5	.90	.51	2.78	.97	2.70	5.58	.50	.000460	64.4	.0186	.0206	72.5	1.02
134		Billings Land and Irrigation Co., silted......................	1,000.0	20.0	2.90	2.32	46.48	2.30	106.93	21.90	2.12	.000295	92.0	.0181	.0184	81.0	1.04
135	A	Grand Canal, hard bed.........	1,000.0	29.0	2.80	1.99	59.57	2.72	161.75	29.20	2.04	.000438	90.8	.0183	.0185	80.5	1.05
136a		Logan, Hyde Park and Smithfield	......	13.7	1.60	1.29	17.80	2.58	45.90	14.80	1.20	.00083	81.5	.0184	.0189	79.0	1.02
137	B	Billings Land and Irrigation Co., clay, sandy.................	750.0	25.5	3.00	2.47	63.10	1.46	92.08	26.90	2.34	.000111	90.5	.0186	.0190	78.4	1.14
138	A	Billings Land and Irrigation Co., same reach.................	750.0	26.5	3.70	2.99	79.20	1.88	148.66	28.40	2.79	.000152	91.1	.0193	.0195	76.5	1.22
139	A	Billings Land and Irrigation Co., same reach.................	750.0	27.0	3.80	3.03	81.50	2.10	171.60	28.70	2.8	.0001867	91.0	.0194	.0195	76.4	1.22
140	A	Billings Land and Irrigation Co., same reach.................	750.0	26.5	3.60	3.17	82.50	1.67	137.89	28.90	2.85	.000127	88.0	.0199	.0202	73.6	1.34
141	A	Billings Land and Irrigation Co., main, clay..................	1,000.0	27.0	3.30	2.65	66.2	2.56	169.50	27.40	2.41	.00033	90.8	.0188	.0190	78.2	1.14
142	B	Maxwell, sandy bed...........	600.0	7.0	1.00	.80	5.57	.42	2.36	7.82	.71	.000067	61.3	.0192	.0229	65.1	1.32
143a	C	Bear River, Corinne Branch, clay	......	4.0	.71	.56	2.23	1.14	2.53	4.46	.50	.00068	61.6	.0194	.0215	69.3	1.10
144a	C	Millville and Providence.......	50.0	10.1	1.60	1.14	11.50	1.94	22.28	10.80	1.07	.00062	74.6	.0195	.0202	73.8	1.15
145	A	Bitter Root Valley Irrigation Co.,	1,000.0	26.0	3.00	2.33	67.60	1.85	112.50	27.55	2.20	.000215	85.3	.0196	.0200	74.6	1.26

146a	B	Logan and Hyde Park, sand......	75.0	14.2	2.05	1.53	21.78	1.08	23.55	15.60	1.40	.00015	75.7	.0197	.0208	71.5	1.28
147a		Mesa lateral (a), sedimented......	550.0	14.8	2.30	2.20	27.91	1.51	42.16	16.52	1.69	.00022	78.3	.0200	.0208	71.7	1.32
148a		Solveson and Co., pebbles........	....	7.5	.83	.53	4.00	1.01	4.03	7.73	.52	.00056	59.2	.0201	.0225	66.1	1.20
149	A	Lateral 7, Turlock District, hard..	1,000.0	21.0	1.40	1.09	22.96	.67	15.44	22.10	1.04	.000098	66.7	.0202	.0225	66.2	1.39
150a		Logan City, gravel bed..........	....	7.2	.18	.14	1.03	.54	.56	7.19	.14	.00135	39.3	.0204	.0272	54.8	1.13
151	B	Billings Land and Irrigation Co....	400.0	24.0	4.00	3.37	80.90	2.56	207.00	27.40	2.85	.000308	86.2	.0204	.0207	72.4	1.40
152a	C	Rist and Goss, silted............	....	6.3	1.00	.57	3.60	.91	3.30	6.30	.57	.00034	65.0	.0204	.0228	65.3	1.08
153a		Wilcox, pebbles and rocks........	400.0	17.1	.80	.51	8.78	1.74	15.29	26.30	.33	.00334	52.1	.0205	.0237	62.9	1.16
154a	B	Old Barnes, silt coat............	....	9.0	1.40	.94	8.50	1.17	9.90	9.00	.95	.00032	67.0	.0206	.0220	67.6	1.32
155	A	Bitter Root Valley Irrigation Co.	750.0	26.5	2.88	....	56.40	2.00	112.50	27.23	2.03	.000312	79.5	.0208	.0211	70.5	1.40
156a	B	Logan and Richmond, clay......	100.0	14.9	2.42	2.15	32.02	2.14	68.56	17.80	1.74	.00046	75.6	.0211	.0217	68.8	1.43
157	A	Bitter Root Valley Irrigation Co.	1,000.0	27.0	2.90	2.21	59.80	1.59	95.31	28.80	2.08	.00020	78.0	.0211	.0216	68.9	1.47
158	A	Billings Land and Irrigation Co., lateral 2..................	400.0	8.4	1.40	.98	8.20	.78	6.37	9.20	.88	.000175	62.2	.0212	.0234	63.6	1.44
159a	B	Logan, Hyde Park and Smithfield	60.0	12.0	2.08	1.72	20.61	2.49	51.36	13.56	1.52	.00077	73.0	.0213	.0219	68.0	1.43
160		Morris, bed ploughed, grassy.....	1,000.0	70.0	4.10	2.98	208.50	.43	89.23	71.90	2.90	.0000107	79.6	.0216	.0224	66.4	1.67
161	A	Hedge, fine granite, few rocks.....	200.0	16.5	2.65	1.94	32.00	2.09	67.00	17.80	1.80	.00044	74.4	.0216	.0221	67.3	1.50
162	A	Birch, Imperial Water Co., No. 1, hard bed..................	1,000.0	10.0	1.60	1.30	13.05	1.34	17.45	11.71	1.11	.0003795	65.0	.0217	.0233	63.9	1.50
163a		Point Lookout, sedimented........	....	35.8	2.25	1.65	58.94	1.48	87.29	36.73	1.60	.00027	71.2	.0218	.0226	65.8	1.54
164		Crowley, bed harrowed, grassy....	1,000.0	27.0	5.10	3.08	83.05	.82	68.29	27.80	2.99	.0000345	80.0	.0219	.0224	66.4	1.68
165a		Bessemer (b), smooth adobe......	1,600.0	18.2	2.90	2.05	37.27	1.55	57.98	19.87	1.88	.00024	72.9	.0219	.0227	65.6	1.59
166a		Bessemer (a), smooth adobe......	1,495.0	16.1	3.50	2.31	37.15	1.56	57.98	18.15	2.04	.00036	57.5	.0281	.0293	50.9	2.49
167	A	Big Ditch high line, silted........	1,000.0	10.5	1.70	1.17	12.32	1.24	15.22	11.65	1.06	.000357	64.0	.0220	.0235	63.4	1.51
168a		Louden, clean sand..............	....	25.0	2.00	1.49	37.30	1.66	62.00	24.50	1.52	.00038	69.0	.0220	.0232	64.3	1.58
169a		Mesa lateral (b), fine silt bed.....	600.0	14.7	2.40	2.00	27.40	1.47	40.32	76.46	1.66	.00026	70.6	.0220	.0230	64.7	1.59
170a		Rio Grande lateral 1 (c), gravel	1,238.0	25.5	1.90	1.46	37.22	3.86	143.60	26.20	1.42	.00220	68.8	.0221	.0230	64.9	1.54
171a		Rio Grande lateral 1, gravel......	5,280.0	....	....	....	19.52	1.39	27.16	32.80	.60	.00362	29.9	.0390	.0457	32.6	3.31
172	A	Santa Ana main, cemented sand...	1,000.0	16.5	1.30	1.15	18.92	1.44	27.16	17.18	1.06	.000481	63.6	.0221	.0237	63.0	1.52
173	A	California Development Co., central main..................	998.0	38.0	5.00	4.26	161.65	2.08	336.91	43.80	3.69	.0001682	83.8	.0221	.0222	67.1	1.69
174	A	Billings Land and Irrigation Co., gravel..................	1,500.0	21.5	2.90	2.36	50.90	2.00	102.22	23.90	2.13	.000335	75.0	.0221	.0226	65.9	1.61
175	A	Salt River Valley................	900.0	17.0	3.40	2.48	42.16	3.12	131.33	19.55	2.16	.000798	75.1	.0222	.0226	65.9	1.61
176a		Lewiston, clay, moss patches.....	....	16.6	2.12	1.66	27.53	1.19	32.72	18.08	1.52	.00020	68.1	.0224	.0235	63.5	1.62
177a	B	Geo. Rist, gravel...............	....	12.0	1.30	.92	11.00	1.15	12.70	12.10	.91	.00040	60.2	.0224	.0244	61.2	1.54
178	A	Big Ditch, sand bed, mud sides...	1,000.0	15.5	3.70	2.43	40.10	2.09	83.68	18.80	2.13	.000377	73.7	.0225	.0230	64.8	1.66
179	B	Bitter Root Valley Irrigation Co.	400.0	27.0	2.75	2.10	56.80	1.63	92.80	28.85	1.97	.000262	71.8	.0226	.0233	64.0	1.68
180	A	Lateral 10, Orland project........	568.0	12.0	1.75	1.24	14.82	1.78	26.35	13.20	1.11	.0007365	62.2	.0228	.0244	61.1	1.62

1 Ref. no.	2 Class	3 Name and description	4 L	5 App. width	6 Max. depth	7 Av. depth	8 a	9 v	10 Q	11 p	12 r	13 s	14 c	15 K's n	16 M's n	17 M's K	18 m
181*a*		Providence Upper, packed	....	6.5	.63	.51	3.29	.71	2.34	6.80	.48	.00043	49.3	.0229	.0267	55.9	1.52
182*a*		Bear River lateral, silt and moss	....	5.5	.95	.71	3.89	1.19	4.63	6.00	.65	.00075	54.0	.0230	.0256	58.1	1.55
183*a*	*B*	Bear River lateral 2, silt, grass	80.0	7.8	.95	.74	5.74	1.38	7.90	8.12	.71	.000875	55.4	.0230	.0254	58.7	1.55
184	*A*	Orland South Main	596.1	21.1	2.50	2.12	44.40	1.90	84.32	23.00	1.93	.0003859	69.7	.0231	.0239	62.3	1.75
185*a*		Walker tract, loam	....	19.5	2.70	1.96	13.32	1.01	38.55	20.90	1.83	.00012	67.8	.0232	.0244	61.2	1.79
186	*A*	River Branch Canal, few cobbles	593.0	16.5	2.40	1.80	29.73	2.82	83.86	17.98	1.65	.001105	66.0	.0236	.0246	60.6	1.78
187*a*		Providence, medium gravel	....	6.4	.90	.82	5.26	1.90	9.98	7.40	.71	.00175	53.8	.0238	.0261	57.0	1.63
188*a*	*C*	College and City, gravel, roots	50.0	3.7	.76	.70	2.59	2.93	7.60	4.73	.55	.00616	50.4	.0238	.0267	55.8	1.58
189*a*	*B*	Logan, Hyde Park and Thatcher	100.0	17.6	2.22	1.74	30.60	1.97	60.23	18.90	1.62	.0006	63.2	.0246	.0256	58.2	1.90
190	*B*	Small ditch, new	350.0	3.5	1.10	.69	2.40	.34	.81	4.15	.58	.0001014	44.0	.0246	.0309	48.3	1.97
191*a*	*B*	College and City, uneven	....	4.4	.88	.80	3.51	1.61	5.66	5.44	.65	.0016	50.2	.0247	.0276	54.0	1.72
192	*A*	Boulder and White Rock	300.0	7.2	.50	.45	3.21	1.00	3.20	7.54	.43	.001246	43.3	.0248	.0298	50.0	1.73
193	*A*	Billings Land and Irrigation Co., gravel	1,000.0	28.0	3.90	3.23	90.25	1.82	164.45	31.16	2.89	.000248	68.2	.0258	.0262	56.9	2.23
194	*A*	South Side Twin Falls, lateral	754.0	10.0	2.00	1.49	14.88	1.75	26.06	11.50	1.29	.000737	56.7	.0259	.0274	54.3	2.02
195	*A*	Billings Land and Irrigation Co.	1,000.0	27.0	4.25	3.45	93.00	2.35	218.33	30.80	3.02	.00088	69.0	.0259	.0261	57.2	2.23
196*a*		Hyrum, rocky, earth bed	....	5.0	.44	.37	1.87	.84	1.57	5.28	.35	.0013	38.9	.0260	.0320	46.5	1.81
197	*A*	Bitter Root Valley Irrigation Co.	1,000.0	27.0	2.80	2.19	59.10	1.61	95.30	29.00	2.04	.00032	63.0	.0260	.0267	55.8	2.15
198	*A*	North Ogden, gravel	800.0	8.5	1.75	1.38	11.71	1.72	20.12	9.77	1.20	.000831	54.5	.0262	.0282	52.8	2.07
199	*A*	Main Branch Turlock district, hard pan	1,000.0	28.0	1.75	1.26	35.24	.99	35.01	27.80	1.27	.000263	54.4	.0262	.0285	52.2	2.14
200	*A*	Billings Land and Irrigation Co., gravel	1,000.0	24.0	3.50	2.67	64.10	2.67	171.34	26.95	2.38	.00072	64.2	.0264	.0269	55.4	2.24
201*a*		Rocky Ford (*a*), loose sand bed	1,000.0	14.5	2.00	1.69	24.44	1.68	41.20	16.08	1.52	.00058	56.5	.0266	.0283	52.6	2.21
202	*A*	Salt Lake City and Jordan	600.0	9.5	2.25	2.19	20.28	1.57	31.86	13.21	1.57	.0004783	57.3	.0267	.0281	53.1	2.19
203*a*	*B*	Loveland and Greely	....	34.0	2.30	1.74	59.20	1.69	100.00	35.00	1.69	.00050	58.2	.0267	.0280	53.2	2.22
204	*A*	Fullerton, loose sand bed	600.0	12.0	1.50	1.15	13.79	1.14	15.72	13.38	1.03	.000493	50.5	.0269	.0297	50.2	2.08
205	*A*	Farmer's, few rocks	600.0	11.0	.90	.61	6.76	1.41	9.52	11.38	.59	.001758	43.5	.0270	.0313	47.6	2.02
206	*A*	Billings Land and Irrigation Co., sand bed	400.0	8.5	1.80	1.16	9.86	1.45	14.28	9.68	1.02	.000812	50.6	.0271	.0296	50.4	2.06

207	*A*	Billings Land and Irrigation Co., same reach	400.0	7.5	1.40	.99	7.46	1.23	9.20	8.98	.83	.000842	46.5	.0277	.0310	48.0	2.18
208	*B*	Billings Land and Irrigation Co., same reach	400.0	7.0	1.10	.87	6.12	1.04	6.37	8.20	.75	.00082	42.1	.0294	.0337	44.5	2.38
209	*A*	Yosemite Power Co.	662.6	3.5	.75	.56	1.95	1.32	2.57	4.14	.47	.003679	31.6	.0274	.0415	35.9	2.73
210	*A*	Parley's Ditch lateral, sand bed	600.0	5.0	1.20	.74	3.70	1.20	4.44	5.63	.66	.001168	43.2	.0278	.0321	46.4	2.15
211*a*		Bessemer (*b*), fine silt, rocks	2,002.0	16.4	3.10	2.04	33.56	1.26	42.35	18.55	1.81	.00028	55.9	.0280	.0295	50.5	2.45
212	*C*	South Side Twin Falls, lateral	718.0	6.5	1.90	1.25	8.12	2.50	20.32	8.05	1.01	.002683	48.1	.0283	.0310	48.0	2.29
213	*B*	Arizona Canal lateral	700.0	5.5	1.70	1.10	6.09	2.36	14.35	6.66	.91	.003088	46.0	.0284	.0319	46.7	2.31
214*a*		Rio Grande lateral No. 1, gravel	5,280.0	43.7	2.40	1.87	81.62	4.66	380.00	23.70	1.87	.00366	56.3	.0284	.0294	50.6	2.46
215	*A*	Beech Imperial Water Co., No. 1, sand bed	1,000.0	8.0	.90	.75	5.97	.87	5.18	8.67	.69	.000594	42.8	.0290	.0327	45.6	2.23
216	*A*	Wheeler, hard bed, loose rocks	1,164.5	10.5	2.00	1.56	16.40	1.18	19.35	12.05	1.36	.000411	49.8	.0292	.0315	47.3	2.52
217*a*		Bear River lateral, clay, irregular	....	8.4	.85	.57	4.79	1.69	8.08	8.56	.56	.0033	39.2	.0293	.0344	43.3	2.26
218*a*		Bear River lateral, similar reach	....	11.1	1.64	1.15	12.79	.61	7.83	11.80	1.08	.00017	45.1	.0295	.0335	44.5	2.59
219	*A*	Billings Land and Irrigation Co., lateral 1	600.0	11.0	2.00	1.29	14.20	.87	12.35	12.35	1.15	.00029	47.8	.0299	.0319	46.7	2.46
220	*A*	Billings Land and Irrigation Co., lateral 1	400.0	7.5	1.25	.99	7.42	1.09	8.08	8.95	.83	.00084	41.3	.0308	.0350	42.6	2.57
221	*B*	Modesto Main, loose sand	930.0	55.0	1.60	.86	47.50	.91	43.05	54.30	.88	.0005165	42.7	.0300	.0342	43.6	2.52
222	*A*	Upper, Riverside, sand, moss	294.9	12.0	2.70	2.30	27.60	1.73	27.83	14.70	1.88	.000634	50.2	.0315	.0330	45.1	2.93
223	*A*	Lower, Riverside, tangent	355.0	11.5	1.80	1.28	14.78	1.60	23.64	12.15	1.22	.0010647	44.4	.0318	.0347	42.9	2.82
224	*A*	Lower, Riverside, same, with curve	844.4	11.5	1.80	1.50	17.25	1.37	23.64	13.05	1.32	.0009095	39.5	.0360	.0395	37.7	3.44
225*a*		Hyrum, gravel bed	....	5.5	.61	.51	2.82	.88	2.47	5.79	.49	.0014	33.6	.0319	.0393	37.9	2.58
226*a*	*B*	Beasley, gravel bed, log sides	....	24.0	.80	.50	12.10	1.10	13.30	25.0	.48	.0014	42.5	.0320	.0310	48.2	1.88
227*a*		Bessemer (*c*), loose stones	1,194.0	15.4	3.20	2.38	36.65	1.16	42.35	17.78	2.06	.00026	50.0	.0321	.0337	44.2	3.09
228	*A*	Lower, from Big Cottonwood	1,000.0	8.0	1.70	1.23	9.82	1.03	10.08	9.20	1.07	.000533	42.8	.0324	.0352	42.3	2.77
229*a*		Smithfield lateral, some cobbles	....	5.1	.67	.58	2.97	.43	1.29	5.70	.52	.000353	32.0	.0329	.0417	35.8	2.83
230	*A*	Yosemite Power Co., Golden Rock	537.0	7.2	1.10	.81	5.82	1.20	6.97	7.95	.73	.001629	34.7	.0346	.0407	36.6	3.03
231	*C*	Billings Land and Irrigation Co., lateral 1	400.0	9.5	1.75	1.03	9.79	1.12	10.95	10.22	.96	.00093	37.3	.0349	.0397	37.6	3.16
232*a*		Logan and Benson Ward, moss	....	21.0	1.61	1.39	29.14	.84	24.59	22.00	1.32	.00033	40.3	.0352	.0388	38.4	3.34
233	*A*	Logan and Hyde Park, gravel	550.0	14.5	1.90	1.60	23.14	1.18	27.38	17.51	1.32	.0006982	38.9	.0364	.0402	37.1	3.51
234*a*	*B*	Hillsboro, rough	....	23.0	2.50	2.18	50.10	1.44	72.00	26.70	1.87	.00060	42.8	.0371	.0387	38.5	3.67
235	*B*	Lateral 2½, Turlock district, sand	1,020.5	23.0	3.10	1.92	44.26	.81	35.99	24.50	1.80	.000217	41.1	.0373	.0401	37.2	3.80
236	*A*	Cochran, gravel	733.8	14.0	2.10	1.58	23.06	1.18	27.15	16.62	1.39	.000695	37.9	.0379	.0416	35.8	3.72
237	*A*	Perrault, hard bed, grass	610.0	11.5	1.60	1.15	13.20	.70	9.28	12.48	1.06	.000398	34.2	.0381	.0440	33.9	3.72

TABLE 112 (*Continued*)

1 Ref. No.	2 Class	3 Name and description	4 L	5 App. width	6 Max. depth	7 Av. depth	8 a	9 v	10 Q	11 p	12 r	13 s	14 c	15 K's n	16 M's n	17 M's C'	18 m
238*a*		Hyrum lateral, rocks, moss	....	6.6	1.20	.84	5.55	.44	2.47	7.20	.77	.00029	29.6	.0393	.0482	30.9	3.80
239	*A*	Orr, hard scoured bed	1,426.0	15.0	2.80	2.11	31.72	1.44	45.80	17.81	1.84	.000746	39.1	.0397	.0423	35.3	4.11
240	*A*	Small ditch, hard bed, débris	308.0	3.9	.60	.44	1.70	.45	.76	4.21	.40	.000919	23.3	.0399	.0547	27.2	3.65
241	*A*	Capurro, few cobbles	300.0	3.2	.90	.86	3.74	.35	.96	4.94	.56	.0003367	25.6	.0403	.0527	28.3	3.86
242*a*		Brigham City Electric Light Co., moss	....	10.7	2.50	1.91	20.44	1.52	31.07	12.60	1.62	.00115	35.2	.0424	.0460	32.4	4.43
243	*B*	New Rutner, gravel bed	600.0	5.5	1.15	.75	4.15	.65	2.69	6.15	.68	.00095	25.6	.0436	.0545	27.3	4.25
244	*A*	Sullivan and Kelly, few cobbles	1,010.0	13.0	3.10	2.17	28.18	1.45	40.93	15.10	1.8	.000894	35.6	.0436	.0463	32.2	4.60
245		Roller, grass slopes	1,000.0	48.0	5.50	4.09	196.34	.40	78.35	50.30	3.90	.000023	42.1	.0461	.0446	33.4	5.42
246*a*		Brigham City, much vegetation	....	19.6	2.38	1.82	35.76	.65	23.40	20.50	1.74	.00028	29.6	.0499	.0553	26.9	5.70
247*a*		Thatcher lateral, much vegetation	....	5.0	.70	.51	2.57	.42	1.08	5.30	.48	.00107	18.4	.0519	.0715	20.8	5.24
248*a*		Thatcher lateral, much vegetation	....	4.1	.82	.70	2.90	.37	1.08	4.98	.58	.00064	19.2	.0529	.0707	21.1	5.49
249	*B*	Small ditch, grass-lined	100.0	5.0	1.00	.64	3.21	.32	1.04	6.01	.52	.00067	17.3	.0544	.0771	19.3	5.83
		Cobble-bottomed															
250*a*	*B*	Beasley	....	16.0	.80	.46	7.4	1.74	12.90	16.6	.44	.00093	87.0	.0220	.0149	100.0	0.54
251	*A*	Bitter Root Valley Irrigation Co.	600.0	27.0	3.00	2.32	62.57	2.27	142.10	27.57	2.27	.00055	60.6	.0262	.0283	52.7	2.41
252	*A*	Upper, from Big Cottonwood	950.0	11.0	1.70	1.39	15.28	1.77	26.90	15.10	1.17	.001012	51.2	.0277	.0299	49.9	2.25
253	*A*	Logan and Northern, grass	630.0	16.2	3.70	2.60	42.72	1.77	75.66	19.00	2.25	.00037	61.3	.0270	.0279	53.4	2.36
254	*A*	Reno, hand-laid riprap	800.0	18.0	6.00	3.92	70.59	3.57	251.79	23.40	3.02	.001129	61.1	.0291	.0294	50.6	2.74
255	*A*	Sullivan and Kelly, laid wall	670.0	10.5	3.30	2.45	25.70	1.59	40.93	15.23	1.81	.000603	48.2	.0324	.0342	43.6	3.05
256*a*		Logan and Hyde Park	....	1.8	.38	.35	.63	1.35	.85	2.32	.27	.00991	25.9	.0337	.0461	32.4	2.64
257*a*		Hyrum lateral	....	3.6	.27	.22	.80	1.02	.81	4.00	.20	.01212	20.7	.0365	.0548	27.2	2.96
258*a*		Smithfield lateral	....	4.6	.29	.24	1.11	1.33	1.48	4.75	.23	.0171	21.1	.0377	.0550	27.1	3.10
259	*A*	Beasley, very little grass	889.2	14.0	.80	.71	9.97	1.82	18.14	15.40	.65	.00584	29.6	.0383	.0468	31.8	3.49
260*a*		**Smithfield lateral, very uneven**	....	4.6	.28	.22	1.06	1.10	1.17	4.70	.23	.0170	17.9	.0423	.0648	23.0	3.74

		Sidehill Cuts with Retaining Walls															
261	*A*	Hedge, plastered wall............	250.0	14.0	3.45	3.08	43.10	1.58	68.00	18.50	2.31	.000132	90.5	.0185	.0190	78.5	1.13
262	*A*	Hedge, earth and gravel bed......	450.0	13.0	3.15	3.76	35.90	1.85	66.50	17.10	2.10	.00030	73.8	.0225	.0229	65.1	1.65
263	*A*	Cove, concrete floor...............	900.0	12.0	2.70	1.68	20.21	2.30	46.61	13.81	1.45	.00080	67.5	.0228	.0235	63.4	1.61
264	*B*	Logan, Hyde Park and Smithfield	337.0	13.0	2.50	1.73	22.49	3.12	70.19	15.24	1.48	.001852	59.7	.0256	.0267	55.8	2.00
265	*A*	Hedge, concrete wall and floor.....	300.0	12.5	3.15	2.88	36.00	1.85	66.50	16.90	2.13	.00044	60.5	.0269	.0280	53.2	2.34
266	*B*	Logan, Hyde Park and Smithfield.	100.0	12.5	2.50	1.78	22.22	3.16	70.19	15.50	1.44	.00237	54.2	.0278	.0293	50.9	2.29
		Miscellaneous Sections															
267	*A*	Lower, Riverside Water Co.......	200.0	10.5	1.50	1.38	14.45	1.32	19.04	12.35	1.17	.00045	57.4	.0249	.0267	55.9	1.89
268	*A*	Lower, Riverside Water Co.......	750.0	10.0	1.80	1.52	15.15	1.26	19.04	12.22	1.24	.0005253	49.1	.0291	.0315	47.3	2.46
269	*B*	Logan, Hyde Park and Smithfield.	265.0	9.5	2.50	2.15	20.40	3.44	70.19	13.42	1.52	.0030	50.9	.0298	.0314	47.4	2.58

INDEX

D